PROTOCOLS FOR MONITORING JUVENILE SALMONID HABITATS IN THE LOWER COLUMBIA RIVER ESTUARY

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Note about Authorship:
This protocol document aims to consolidate and provide technical guidance for those monitoring the ecology of tidal wetlands and waterways in the Columbia River. Much like a recipe book borrows from many cooks who came before it, this document is a collection of numerous research methods and approaches that have been developed and refined over time. We strive to offer updated technical guidance and resources to assist anyone monitoring the tidal wetlands of the Lower Columbia River Estuary. We will regularly incorporate partner feedback and new methods into this living document, proving a version history of these ongoing developments.

The original Columbia Estuary Ecosystem Restoration Program (CEERP) protocols document, titled "Protocols for Monitoring Habitat Restoration Projects in the Lower Columbia River and Estuary" by Roegner et al., published in 2009, provides the historical context for these method updates (link). This critical work laid the foundation for the development and refinement of our monitoring protocols. Our updated methods build upon this groundwork, integrating changes based on new knowledge and advancements in the field. It is important to note that while this protocol document offers comprehensive technical guidance and best practices for monitoring in the estuary, it does not modify any existing CEERP mandated monitoring requirements. These mandates remain as outlined in the historic Roegner et al. document and other relevant CEERP documents. Readers seeking detailed information on these mandates are advised to refer to these historic sources.

Furthermore, this document, prepared by the Lower Columbia Estuary Partnership, extends beyond the scope of the CEERP. It serves as a guiding monitoring protocol document supporting our and our partners diverse programs and research efforts. This broader application reflects our commitment to comprehensive and adaptable monitoring strategies that can be applied across a range of environmental and ecological studies in the estuary region, ensuring the continued relevance and applicability of our work in various contexts.

The regional discussion of creating this protocol update has officially been at play since 2018, and since this time numerous workgroups, presentations, and meetings with regional partners and project sponsors have informing their ongoing development. April Silva's master's thesis, published in 2020, was instrumental in framing this update, while Sarah Kidd’s dissertation, published in 2017, significantly contributed to the inclusion of new methods. Additionally, research methods published annually in the Lower Columbia Estuary Partnership’s Action Effectiveness Monitoring and Research (AEMR) and Ecosystem Monitoring Program (EMP) reports, authored by S. Rao, I. Edgar, S. Kidd, M. Schwartz, and other research partners, have been updated and incorporated into this document.

Each section of this methods update provides specific authorship and citation notes, which should be cited directly as required.

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Change Log:

1) Version 1.0 - Sept 2023
    a) Initial publication
2) Version 1.1 - Oct 2023.
    a) Fixed typos and clarity issues idenfied throughout document
    b) Added Full List of Authors
    c) Added Change Log
3) Version 1.2 - Dec 2023.
    a) Clarification on CEERP Mandates: Added text to emphasize that the current protocol document provides technical guidance and best practices for monitoring in the estuary but does not alter any existing CEERP mandated monitoring requirements. This addition directs readers to the historic Roegner et al. document and other relevant CEERP documents for detailed information on these mandates.
    b) Clarification of Scope: Updated the document to reflect its preparation by the Lower Columbia Estuary Partnership and its application beyond the CEERP. The new text highlights the document's role as a guiding monitoring protocol for diverse programs and research efforts undertaken by the partnership and its partners. This edit underlines the commitment to comprehensive and adaptable monitoring strategies applicable across a range of environmental and ecological studies in the estuary region.
    c) Fixed author idenfied typos in Chapter 6.

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Acronym List

Action Effectiveness Monitoring and Research	AEMR
Ecosystem Monitoring Program	EMP
Bonneville Power Administration	BPA
Columbia Estuary Ecosystem Restoration Program	CEERP
Columbia River Estuary Study Taskforce	CREST
Lower Columbia Estuary Partnership	LCEP
Oregon Watershed Enhancement Board	OEWB
United States Geological Survey	USGS
Oregon Department of Environmental Quality	ODEQ
Washington Department of Ecology	WDE
Water Surface Elevation	WSE
Dissolved Oxygen	DO
Unmanned Aerial Vehicle (e.g., drone)	UAV
Ground Control Point	GCP
Digital Surface Model	DSM
Digital Elevation Model	DEM
Digital Terrain Model	DTM
Global Positioning System	GPS
Real-time Kinematic Positioning	RTK
Passive Integrated Transponder Tag	PIT Tag
Polyvinyl Chloride (pipe material)	PVC
Oxidation Reduction Potential	ORP
Total Dissolved Solids	TDS

Introduction

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The Lower Columbia Estuary Partnership (LCEP) is dedicated to the conservation and restoration of the Lower Columbia River and Estuary (LCRE), embracing a wide-ranging approach that encompasses diverse ecosystems and the complex interplay of environmental factors. Our work transcends specific programs, integrating a broad spectrum of research, conservation, and restoration efforts aimed at understanding and improving the health and resilience of the LCRE.

At the heart of our mission is the development of comprehensive monitoring and evaluation strategies. These strategies are crucial for assessing the condition of the estuary, guiding restoration initiatives, and fostering adaptive management across various environmental contexts. The need for such adaptable and rigorous approaches is more critical than ever, as we face evolving challenges and opportunities in environmental stewardship.

This protocol document, prepared by the LCEP, stands as a testament to our commitment to collaborative and informed ecosystem management. While it builds upon the foundation laid by seminal works such as the 'Protocols for Monitoring Habitat Restoration Projects in the Lower Columbia River and Estuary' by Roegner et al. in 2009, its scope extends significantly beyond any single program, such as the Columbia Estuary Ecosystem Restoration Program (CEERP). It offers a versatile framework applicable to a multitude of conservation and research endeavors in the LCRE and similar ecosystems.

Our document provides detailed technical guidance and best practices for a variety of monitoring activities, reflecting the latest knowledge and advancements in the field. It is designed to be a dynamic resource, evolving with ongoing research and practical experience. This approach ensures that the protocols remain relevant and effective for a wide range of environmental and ecological studies, not just within the CEERP, but across multiple initiatives aimed at ecosystem conservation and restoration. It's important to clarify that while this document offers extensive guidance, it does not modify any existing mandates, such as those outlined in the CEERP. For specific details on these mandates, readers are encouraged to refer to the original sources, including the Roegner et al. document.

As a comprehensive guide, this document serves as a valuable tool for practitioners, scientists, and stakeholders engaged in various aspects of environmental conservation and research. By aligning with broader conservation goals and supporting adaptive management, it aims to enhance the effectiveness and consistency of monitoring efforts across diverse projects and research initiatives.

In presenting this updated protocol document, the LCEP underscores its broader vision for the stewardship of the LCRE. Our goal is to share knowledge, experience, and technical expertise widely, fostering a collaborative approach to ecosystem management. Through this document, we aim to contribute to the overall health and understanding of the LCRE ecosystem, supporting a diverse range of conservation and restoration activities that extend far beyond the confines of any single program.

1.1 What and Why We Monitor: Developing a Plan and Selecting Metrics

Restoration Ecology - Understanding the Importance of Monitoring

Restoration ecology is a scientific discipline focused on restoring and improving the structure, function, and biodiversity of degraded ecosystems (SER 2004; Apostol et al. 2006; Simenstad et al. 2006; Palmer and Rulh 2015). In the broader context of ecosystem restoration and conservation, exemplified by initiatives like the Columbia Estuary Ecosystem Restoration Program (CEERP), monitoring plays a critical role in informing adaptive management and advancing our understanding of these complex systems. Monitoring is essential in restoration ecology for several reasons. First, it allows us to assess the effectiveness of restoration actions by tracking changes in ecological conditions over time. By collecting data on key indicators, such as vegetation composition, species diversity, habitat connectivity, and hydrological patterns, we can evaluate the success of restoration projects and make informed decisions regarding management strategies (Jones et al. 2009; Suding et al. 2015).

Second, monitoring provides valuable information for adaptive management. Restoration projects are often long-term endeavors, and adaptive management involves adjusting management actions based on monitoring results and scientific understanding. By regularly monitoring and evaluating the outcomes of restoration efforts, we can identify areas where adjustments are needed, learn from successes and failures, and refine our approaches to achieve desired ecological outcomes (Hobbs and Harris 2001; Palmer et al. 2005; Suding et al. 2015).

Third, monitoring contributes to the broader scientific understanding of ecological processes and the functioning of ecosystems. By collecting data in a consistent and standardized manner, we can compare results across different projects, study areas, and landscapes. This enables us to address larger research questions that extend beyond individual sites and provide insights into regional patterns, ecological thresholds, and the cumulative effects of multiple restoration projects (Zedler and Callaway 1999; Warren et al. 2002)

Ecological Research and Monitoring Plans - Defining Data Collection and Analysis

Developing a comprehensive and well-designed monitoring plan is essential for effective restoration and ecological research. A clear plan ensures that monitoring efforts are aligned with project goals and objectives and that the right metrics and methods are selected.

Measurable goals and objectives are the foundation of a monitoring plan. They provide a framework for defining the desired ecological outcomes and guide the selection of appropriate metrics and indicators to assess project success. Goals may include restoring specific habitat types, enhancing biodiversity, improving water quality, or increasing the presence of target species such as juvenile salmonids. Objectives should be specific, measurable, achievable, relevant, and time-bound (SMART) to facilitate accurate monitoring and evaluation (Palmer et al. 2005).

Selecting the correct metrics is crucial for monitoring the progress and outcomes of restoration projects. Metrics should be directly linked to the project goals and objectives and should capture key ecological processes and responses. Commonly used metrics in restoration monitoring include vegetation characteristics (e.g., species composition, cover, and structure), hydrological parameters (e.g., water levels, flow velocities), soil properties, and the presence of indicator species (Zedler and Kercher 2005; Suding et al. 2015).

Determining the appropriate monitoring frequency and duration is another important aspect of the monitoring plan. Monitoring should occur at regular intervals to capture temporal variability and long-term trends. The duration of monitoring should be sufficient to detect changes and provide a robust assessment of project outcomes. The specific monitoring frequency and duration will depend on the objectives of the project, the ecological processes being monitored, and resource constraints (Palmer et al. 2005).

Data analysis is a critical step in the monitoring process. It involves applying appropriate statistical techniques to the collected data to derive meaningful insights and draw reliable conclusions. Analysis methods may include comparing pre- and post-restoration data, conducting statistical tests to assess differences between treatment and control sites, and exploring relationships between ecological variables. The analysis plan should be developed in advance and aligned with the project goals, objectives, and the specific monitoring design (Palmer et al. 2005; Suding et al. 2015).

Defining hypotheses and expected outcomes is a fundamental aspect of monitoring and research, not only within the Columbia Estuary Ecosystem Restoration Program (CEERP) but also in broader environmental conservation and restoration efforts. Hypotheses provide a framework for setting specific goals and expectations, enabling us to test whether restoration actions have achieved the desired outcomes. Clear hypotheses help guide the selection of appropriate monitoring metrics, analysis methods, and statistical tests, ensuring that monitoring efforts are focused and efficient. In addition to their scientific significance, hypotheses play a crucial role in regulatory contexts. Regulatory agencies often require explicit hypotheses and monitoring plans to assess the success of restoration projects and make informed decisions. By clearly defining hypotheses and expected outcomes, we can provide a robust scientific basis for evaluating project effectiveness and compliance with regulatory requirements. This proactive approach ensures that monitoring efforts contribute not only to adaptive management and scientific understanding but also to the regulatory process, promoting transparency and accountability (Palmer et al. 2005; Suding et al. 2015).

Considering Ecological Factors Beyond Project Boundaries

In ecological restoration, it is essential to recognize that the impacts and influences on ecosystems often extend beyond the boundaries of individual projects or study areas. The interconnected nature of ecological systems necessitates a comprehensive understanding of the larger landscape and regional context in which restoration actions occur. By collecting data in a consistent manner across multiple projects and sites, we can effectively address broader research questions and gain insights into the ecological dynamics of the Lower Columbia River Estuary.

In ecosystem restoration and conservation, recognizing the need to consider ecological factors beyond project boundaries is crucial. Employing standardized monitoring approaches enhances our understanding of the interconnectedness of ecosystems, allowing us to identify common patterns, trends, and drivers of change across diverse landscapes. This broader perspective is instrumental in informing decision-making processes, targeting management actions, and maximizing the effectiveness of restoration efforts.
Collecting data in a consistent manner across multiple projects and sites also enables us to leverage information and resources from various sources, including the Ecosystem Monitoring Program (EMP) and the Action Effectiveness Monitoring Program (AEMR). These regional monitoring programs provide valuable insights into the ecological conditions and responses of the Lower Columbia River Estuary at a

larger scale. By integrating data from multiple sources, we can achieve a more comprehensive understanding of the estuarine ecosystem and its restoration needs.

By considering ecological factors beyond project boundaries, we can identify potential stressors, cumulative impacts, and broader ecological trends that may influence the success of restoration actions. This broader perspective allows us to make more informed decisions, prioritize restoration efforts, and implement adaptive management strategies that address the complex ecological challenges of the Lower Columbia River Estuary.

Through collaboration, coordination, and data sharing, we can bridge the gap between individual restoration projects and foster a holistic approach to ecosystem restoration. By embracing this collaborative mindset, we can contribute to the long-term conservation and restoration of the Lower Columbia River Estuary and promote the sustainability of its ecosystems for future generations.

Please note that while this document primarily focuses on monitoring best practices and protocols, it recognizes the contributions of programs like the CEERP, the Ecosystem Monitoring Program (EMP), and the Action Effectiveness Monitoring Program (AEMR). For a deeper historical understanding of these specific programs, we refer readers to other sources. However, the main purpose of this document extends beyond the CEERP to provide practical guidance and recommendations for a range of monitoring activities under the broader auspices of the Lower Columbia Estuary Partnership and our research partners. This approach enables practitioners, scientists, and stakeholders to assess the success of diverse restoration actions, inform decision-making processes, and contribute to our evolving understanding of the Lower Columbia River Estuary ecosystem in a more comprehensive manner.

1.2 Setting Up a Monitoring Plan

Establishing Measurable Goals, Objectives, Hypotheses, and Trigger Tables

A well-designed monitoring plan starts with clearly defined and measurable goals and objectives. These goals and objectives provide a framework for understanding the desired outcomes of the restoration project and serve as the basis for developing hypotheses and trigger tables that guide the choice of monitoring metrics.

Measurable goals and objectives in a restoration project outline the specific outcomes or targets that are to be achieved. For example, in a tidal reconnection project with an emphasis on restoring natural hydrology, tidal channel development, water quality, and native wetland composition, the goals may include achieving a specific increase in tidal influence, the establishment of functional tidal channels, improvements in water quality parameters (e.g., dissolved oxygen levels, temperature, nutrient concentrations), and the successful establishment of native wetland vegetation.

Once measurable goals and objectives are established, hypotheses can be formulated to test specific expectations or predictions about the outcomes of the restoration actions. Hypotheses help guide the selection of monitoring metrics by identifying the key variables and relationships that need to be monitored to evaluate the success of the project. For example, a hypothesis for the tidal reconnection project may be that increased tidal influence will lead to increased frequency and depth of flooding and enhanced native wetland plant community composition.

With hypotheses in place, a trigger table can be developed to define the thresholds or criteria that will trigger specific actions or interventions based on the monitoring data. The trigger table serves as a decision-making tool, indicating when and what actions should be taken based on the observed values of the monitoring metrics. It helps ensure that any deviations from the desired conditions or targets are promptly addressed. For instance, the trigger table may specify thresholds for water quality parameters, such as dissolved oxygen levels and nutrient concentrations, that, if exceeded, would trigger further investigations or management actions.

Here is an example of how the project goals and objectives can be translated into hypotheses and a trigger table with specific monitoring metrics and thresholds:

Project Goal 1: Restore Natural Hydrology
Objective 1: Increase tidal influence within the project area by reconnecting tidal flows.
Hypothesis: Reconnecting tidal flows will result in increased water levels and improved hydrological conditions within the project area.

Trigger Table for Project Goal 1:

Project Objectives	Monitoring Metrics	Baseline Conditions	Monitoring Frequency	Monitoring Techniques	Trigger Applicability	Adaptive Measure or Action
1: Restore Natural Hydrology	Water Levels	Pre-Restoration Baseline	Continuous	Hobo Data Loggers	Water levels remain below 2 yr. flood threshold	Project Review Team assessment

Similarly, other project goals and objectives can be translated into hypotheses and trigger tables with relevant monitoring metrics and thresholds:

Project Goal 2: Enhance Tidal Channel Development
Objective 1: Establish functional tidal channels to support tidal connectivity and habitat diversity.
Hypothesis: Creating functional tidal channels will result in increased tidal connectivity and habitat diversity within the project area.

Trigger Table for Project Goal 2:

Project Objectives	Monitoring Metrics	Baseline Conditions	Monitoring Frequency	Monitoring Techniques	Trigger Applicability	Adaptive Measure or Action
2: Enhance Tidal Channel Development	Channel Cross-sections	Post-Construction As-Built	Annual	Visual and Channel Cross-section surveys	Presence of head cut or fish passage barrier	Project Review Team assessment

Project Goal 3: Improve Water Quality
Objective: Increase water quality across the site by reducing water temperatures for aquatic life.
Hypothesis: Implementing measures such as shade provision, riparian vegetation restoration, and water

flow management to reduce water temperatures will lead to improved water quality within the project area.

Trigger Table for Project Goal 3:

Project Objectives	Monitoring Metrics	Baseline Conditions	Monitoring Frequency	Monitoring Techniques	Trigger Applicability	Adaptive Measure or Action
3: Improve Water Quality	Water Temperature	Pre-Restoration Baseline	Continuous	Hobo Data Loggers	Dramatic increase in >19 °C days	Project Review Team assessment

Project Goal 4: Restore Native Wetland Plant Composition
Objective: Establish diverse and thriving native wetland vegetation communities.
Hypothesis: Implementation of restoration actions will result in the establishment of diverse and thriving native wetland vegetation communities within the project area.

Trigger Table for Project Goal 4:

Project Objectives	Monitoring Metrics	Baseline Conditions	Monitoring Frequency	Monitoring Techniques	Trigger Applicability	Adaptive Measure or Action
4: Restore Native Wetland Plant Composition	Wetland Plant Community and Soil Conditions	Pre-Restoration Baseline	Pre, 1, 3, 5, 10 years	Visual, Transects, UAV Imagery	>25% bareground or invasive species abundance	Project Review Team assessment

The trigger table provides a summary of the monitoring metrics, baseline conditions, monitoring frequency, monitoring techniques, trigger applicability, and potential adaptive measures or actions for each project objective. These metrics and thresholds are aligned with the specific goals and objectives of the restoration project, allowing for effective monitoring and adaptive management. It is important to note that the examples provided are for illustrative purposes only and should be tailored to the unique characteristics of each project and site. The specific monitoring metrics, baseline conditions, and trigger thresholds may vary depending on factors such as the ecological context, restoration goals, and regulatory requirements.

Furthermore, it is crucial for the restoration team and funder to work together to determine the monitoring triggers for adaptive management before the restoration activities commence. These triggers serve as decision points that prompt the Project Review Team to assess progress and make informed decisions for ongoing restoration efforts. By establishing these triggers in advance, the team can proactively address any deviations from the desired conditions or targets, ensuring that the restoration project stays on track and achieves its intended outcomes.

Note: The information in these examples is intended to provide guidance and serve as a starting point, but it is essential to tailor the monitoring plan to the specific project and site conditions to ensure its effectiveness.

Statistical Analysis and Design in Restoration Monitoring

In any restoration project, data forms the bedrock upon which outcomes are evaluated and future strategies are decided. Once a robust monitoring plan is in place and the deluge of data begins, statistical analysis emerges, providing direction and clarity. Proper statistical design ensures not only that the collected data is insightful but that its interpretation leads to actionable conclusions on the restoration efforts.

When initiating monitoring activities, envision them as formal experiments or surveys. Establishing control and treatment groups, implementing replication, and advocating for randomization are all quintessential. This ensures that subsequent data interpretations are backed by solid statistical foundations. Depending on the type and distribution of the data, one may employ a range of tests, from t-tests and ANOVAs to chi-square tests. Furthermore, given the rich interconnections often observed between environmental metrics, multivariate analyses like Multiple Nonmetric Dimensional Scaling (NMDS) and Principal Component Analysis (PCA) can offer deeper insights. For an excellent primer on statistical analysis and study design we recommend the Handbook of Biological Statistics by John H. McDonald which is available free online here: https://www.biostathandbook.com/ (McDonald 2014).

Amid all this data crunching, one methodology stands out for its application in restoration contexts: the **Progressive-Change Before-After Control-Impact Paired Series (BACIPS)** design. Rooted in the Before-After Control-Impact (BACI) methodology, it's tailored for discerning intervention impacts from natural variations, be it seasonal changes, climate shifts, or other external factors. The foundational BACI compares a restoration site to one or more untouched sites before and after interventions. However, BACIPS expands this by including multiple reference sites, enhancing our understanding of natural variances, and offering more precise impact assessments.

Progressive-Change Before-After Control-Impact Paired Series (BACIPS) Design for Restoration Monitoring

In restoration projects, it's essential to discern the impacts of interventions from natural variations, whether they're due to seasonal changes, climate variability, or other environmental factors. One rigorous approach to tackle this challenge is the **Progressive-Change Before-After Control-Impact Paired Series (BACIPS)** design.

Understanding BACI Methodology: The foundational concept behind BACIPS is the **Before-After Control-Impact (BACI)** design. This method involves comparing a restoration site (impact site) with one or more control sites that have not undergone restoration, both before and after the restoration intervention (Green, 1979; Stewart-Oaten and Bence, 2001, Connor et al. 2016). By contrasting these differences, any changes due to the intervention can be isolated from those that occur naturally or from other external influences.

The Evolution to BACIPS: BACI designs are sometimes limited when there are multiple potential reference or control sites. By adapting the BACI design to include multiple reference sites, we arrive at the BACIPS methodology. This approach provides a more robust understanding of natural variations and aids in improving the precision of impact assessments (Thiault et al. 2017).

Advantages of BACIPS in Restoration Monitoring:

1. **Addressing Natural Variability:** BACIPS offers a nuanced understanding by accounting for natural climate and seasonal variability, ensuring that any observed changes post-restoration are genuinely attributable to the intervention rather than external factors.
2. **Flexibility:** This design allows for progressive modifications. As the restoration project evolves, sites can be added or removed, offering adaptability without compromising the integrity of the monitoring process.
3. **Enhanced Precision:** By leveraging multiple control sites, BACIPS provides a broader baseline, reducing the chance of spurious results and offering a more precise representation of the restoration's impact.

For those delving deeper into the methodology, the work of Thiault et al. (2017) titled "Progressive-Change BACIPS: A Flexible Approach for Environmental Impact Assessment" offers comprehensive insights. Additionally, this article provides an in-depth understanding of the practical applications and considerations in implementing the BACIPS design.

When integrating this into a restoration monitoring protocol, it's essential to carefully select control sites, ensure consistent data collection methodologies across all sites, and employ rigorous statistical analyses to discern genuine impacts from natural variations.

Incorporating Cultural Perspectives in Monitoring Planning

When designing and implementing a restoration project, it is essential to consider and incorporate cultural perspectives and values from local communities. By doing so, we can ensure that the restoration efforts align with the cultural heritage and aspirations of the Indigenous peoples and other stakeholders. This inclusive approach recognizes the importance of cultural diversity and acknowledges the interconnectedness of ecological restoration and cultural well-being. Moreover, considering cultural perspectives during restoration design and development sets the foundation for incorporating these values into the monitoring process. By integrating cultural values and knowledge systems, the monitoring plan can be tailored to capture ecological indicators that are meaningful to the community, align with cultural values, and reflect the desired outcomes of the restoration project.

Cultural beliefs and requirements may influence the selection of monitoring metrics, trigger thresholds, and adaptive measures. It is essential to consult with Indigenous communities and cultural resource experts to understand their perspectives and incorporate their input into the monitoring plan. This collaborative approach not only fosters mutual respect and understanding but also enhances the overall effectiveness and success of the restoration project.

By considering cultural beliefs and requirements, along with scientific principles and restoration goals, we can develop monitoring plans that are culturally sensitive, socially inclusive, and ecologically informed. This holistic approach not only strengthens relationships between stakeholders but also fosters a deeper appreciation for the interconnectedness of nature and culture, paving the way for more sustainable and meaningful restoration outcomes.

This addition emphasizes the importance of cultural considerations and inclusivity in the monitoring planning process, highlighting the benefits of incorporating traditional knowledge and engaging with Indigenous communities. It underscores the need for a collaborative and holistic approach that respects cultural practices and values, ultimately enhancing the restoration project's effectiveness and promoting a deeper understanding of the interconnectedness of ecosystems and human well-being.

Below are some resources that might be helpful when exploring the ideas around culturally responsive monitoring and restoration planning:

1) Smith, L. T. 2012. Decolonizing methodologies: Research and Indigenous peoples 2nd ed.. Zed Books. This book provides valuable insights into decolonizing research methodologies and emphasizes the importance of incorporating Indigenous perspectives and knowledge systems in monitoring and research.
2) Battiste, M., & Henderson, J. Y. Eds.. 2000. Protecting Indigenous knowledge and heritage: A global challenge. Purich Publishing. This edited volume explores the challenges and strategies for protecting Indigenous knowledge and heritage, including considerations for incorporating Indigenous perspectives in monitoring and conservation efforts.
3) Martinez, A. R., & Trosper, R. L. 2015. Indigenous knowledge and scientific knowledge: Enhancing collaboration for environmental management and governance. Ecological Applications, 253, 732-739.This article discusses the potential benefits of integrating Indigenous knowledge and scientific knowledge in environmental management and governance, highlighting the importance of respectful collaborations that incorporate cultural perspectives.
4) Wilson, S. 2008. Research is ceremony: Indigenous research methods. Fernwood Publishing. This book explores Indigenous research methodologies and provides guidance on conducting research in a culturally appropriate and respectful manner, which can be applied to monitoring planning as well.
5) Tengö, M., Brondizio, E. S., Elmqvist, T., Malmer, P., Spierenburg, M., & Vos, M. 2014. Connecting diverse knowledge systems for enhanced ecosystem governance: The multiple evidence base approach. Ambio, 435, 579-591.This article discusses the importance of integrating diverse knowledge systems, including Indigenous knowledge, in ecosystem governance. It provides insights into approaches that bridge different knowledge systems for effective monitoring and decision-making.

1.3 General Considerations: Best Monitoring Practices in the Office and Field

Efficient and effective monitoring practices extend beyond the collection of data in the field. Proper data management, field protocols, and compliance with permit requirements are essential for successful monitoring programs. Consider the following factors:

Field Protocols and Safety Measures

Field protocols and safety measures are essential to maintain the well-being of monitoring teams and ensure accurate data collection, especially in environments with unique safety considerations. When conducting fieldwork in the Estuary, it is important to be aware of specific safety concerns such as tidal mudflats, extreme weather, lack of cell phone service, and rugged terrain. In addition to general safety practices, it is crucial to consider the following:

- Essential field equipment and supplies: Prepare a checklist of necessary field equipment, such as maps, navigation tools, water, first aid kits, communication devices, and any specialized equipment specific to the monitoring activities (Baker & Freitag, 2020). Regularly inspect and replenish supplies to ensure they are readily available during fieldwork.

- Field safety protocols: Develop and communicate clear safety protocols for all field personnel, including procedures for emergencies, communication plans, and adherence to local regulations and guidelines (Heller & Zavaleta, 2017). Conduct regular safety training and refresher sessions to reinforce safe practices and minimize potential risks.

- Compliance with permit requirements: Understand and comply with all applicable permits and regulations relevant to the monitoring activities, including any airspace considerations, access restrictions, or other specific requirements (McMahan et al., 2019). Maintain accurate records of permits, approvals, and any associated conditions to ensure compliance and mitigate potential legal or regulatory issues.

When considering best practices for safety while conducting fieldwork in the Estuary, we highly recommend a thorough review of well-established resources. While these resources provide a foundation for safety considerations, it is crucial to conduct independent research to tailor a comprehensive safety plan that takes into account the unique conditions expected in the field and the specific activities to be undertaken by the team. This proactive approach will ensure that safety measures are effectively designed and implemented, safeguarding the well-being of monitoring teams and promoting a secure fieldwork environment. Below is a curated list of valuable field safety guides and resources that can serve as a starting point for researchers:

- Field Safety for Biologists: A Handbook of Mitigation Measures for Reducing Risks during Fieldwork by Department of Integrative Biology University of South Florida.
- Field Safety Guidelines for Ecologists (multiple resources) by the Ecological Society of America.
- Safety for Field Research (multiple resources) by Oregon State University.
- OSHA Field Safety and Health (check current regulations) by the Occupational Safety and Health Administration (OSHA).
- Safety Practices for Field Biologists (a series of safety manuals) by the U.S. Fish and Wildlife Service.

Please note that while the provided URLs were functional at the time of writing, it is important to acknowledge that the internet is constantly evolving, and the availability of specific resources may change. Nevertheless, this list serves as a valuable starting point for researchers to explore field safety guides and resources. The resources mentioned above provide valuable guidance and information on field safety practices, emergency procedures, and risk mitigation strategies. By reviewing these resources and conducting independent research, monitoring teams can enhance their understanding of field safety and ensure the well-being of team members. These resources will help promote safe practices and accurate data collection in the dynamic environment of the Estuary.

Data Reporting Requirements

Accurate and timely data reporting is essential for effective monitoring and regulatory compliance. It is important to familiarize yourself with the reporting requirements of relevant agencies and stakeholders. Consider the following:

- Data reporting across multiple agencies: Different agencies may have specific formats, templates, and submission deadlines for reporting monitoring data. Understand the reporting needs of each agency involved in the project (e.g., Bonneville Power Administration, Oregon Department of Ecology, Washington Department of Ecology) and ensure data is presented in the required format.

Be proactive and check with the project partners to ensure data reporting requirements are met for all parties involved.

- Adherence to reporting guidelines: Follow the guidelines provided by each agency for reporting monitoring results, including specific parameters, units of measurement, and quality assurance/quality control procedures (Gray et al., 2014). Include all necessary metadata and documentation to facilitate data interpretation and evaluation.

Data Management and Record Keeping

Effective data management and record-keeping practices are critical for maintaining the integrity and accessibility of monitoring data throughout the project lifecycle. Consider the following key considerations:

- Comprehensive and organized data management: Implement a systematic approach to data collection, storage, and archiving to maintain data integrity and facilitate future analyses (Millennium Ecosystem Assessment, 2005). This includes establishing clear naming conventions, file organization, and version control to ensure data can be easily located and understood by multiple users.

- Long-term record-keeping: Establish protocols for maintaining a complete record of monitoring activities, including field notes, data sheets, photographs, and any other relevant information (Burgman et al., 2011). This ensures the continuity of monitoring efforts and allows for future reference and analysis.

- Shifting technology and data accessibility: Stay updated with evolving technologies and data storage methods to ensure compatibility and accessibility over time (Wood et al., 2013). Regularly review and update data management practices to leverage advancements in technology and improve efficiency.

- Folder and file organization: Maintain a well-structured folder system for easy access and sharing of data among project team members and stakeholders (Colloff et al., 2021). Clearly label folders and files with descriptive names, dates, and version numbers for easy identification and retrieval.

Data Management, Analysis, and Reporting

Data management, analysis, and reporting are critical components of a monitoring plan. This section provides an overview of these processes, acknowledging that each subsequent section within the document will provide detailed guidance on specific aspects. Consider the following key points: Comprehensive data management: Develop a data management plan that outlines procedures for data organization, storage, quality control procedures, and documentation standards (Michener et al., 2012). Clearly define roles and responsibilities for data management and establish protocols for data backup, security, and version control.

- Data analysis methods: Determine appropriate statistical and analytical methods to analyze the collected data in alignment with the project's goals and objectives (Anderson & Thompson, 2004). Consider using statistical software or data visualization tools to aid in data analysis and interpretation (also see Section 1.2).

- Quality assurance/quality control: Implement rigorous quality assurance/quality control procedures to ensure data accuracy, precision, and reliability (Gray et al., 2014). This includes regular calibration and maintenance of monitoring equipment, adherence to standardized protocols, and data validation procedures.

- Reporting and communication: Develop a reporting framework that includes regular reporting intervals and effective communication channels with project stakeholders and regulatory agencies (Millennium Ecosystem Assessment, 2005). Clearly present the findings, conclusions, and recommendations in a format that is accessible and understandable to both technical and non-technical audiences.

- Data archiving and accessibility: Establish a plan for long-term data archiving and accessibility to facilitate future analysis, research, and monitoring efforts (Whitlock et al., 2010). Consider using appropriate data repositories or platforms that adhere to data sharing and accessibility standards.

By incorporating these best practices in data management, analysis, and reporting, monitoring programs can ensure the accuracy and reliability of the collected data, facilitate effective decision-making, and contribute to the overall success of the restoration project. It is important to note that the specific details and requirements of data management, analysis, and reporting may vary depending on the project's scope, objectives, and regulatory requirements.

To ensure the best practices for data collection, management, and reporting, it is important to consider the following recommendations:

- Comprehensive and organized data management: Implement a systematic approach to data collection, storage, and archiving. This includes establishing clear naming conventions, file organization, and version control to ensure data can be easily located and understood by multiple users.

- Long-term record-keeping: Establish protocols for maintaining a complete record of monitoring activities, including field notes, data sheets, photographs, and any other relevant information. This ensures the continuity of monitoring efforts and allows for future reference and analysis.

- Shifting technology and data accessibility: Stay updated with evolving technologies and data storage methods to ensure compatibility and accessibility over time. Regularly review and update data management practices to leverage advancements in technology and improve efficiency.

- Folder and file organization: Maintain a well-structured folder system for easy access and sharing of data among project team members and stakeholders. Clearly label folders and files with descriptive names, dates, and version numbers for easy identification and retrieval.

- In addition to these considerations, it is essential to follow best practices for data management, analysis, and reporting.

- Develop a data management plan that outlines procedures for data organization, storage, quality control procedures, and documentation standards. Clearly define roles and responsibilities for data management and establish protocols for data backup, security, and version control.

- Determine appropriate statistical and analytical methods to analyze the collected data in alignment with the project's goals and objectives. Consider using statistical software or data visualization tools to aid in data analysis and interpretation.

- Implement rigorous quality assurance/quality control procedures to ensure data accuracy, precision, and reliability. This includes regular calibration and maintenance of monitoring equipment, adherence to standardized protocols, and data validation procedures.

- Develop a reporting framework that includes regular reporting intervals and effective communication channels with project stakeholders and regulatory agencies. Clearly present the findings, conclusions, and recommendations in a format that is accessible and understandable to both technical and non-technical audiences.

- Establish a plan for long-term data archiving and accessibility to facilitate future analysis, research, and monitoring efforts. Consider using appropriate data repositories or platforms that adhere to data sharing and accessibility standards.

These best practices emphasize the critical need for accurate metadata and proper data management techniques. Field ecologists should be aware that short-term projects can often turn into long-term endeavors, and individual project data may need to be incorporated into regional databases. It is crucial to prioritize data quality and usability to ensure the long-term value and applicability of monitoring data (Millennium Ecosystem Assessment, 2005; Burgman et al., 2011; Michener et al., 2012; Gray et al., 2014; Whitlock et al., 2010). While this section provides an overview of data management, analysis, and reporting processes, researchers are encouraged to conduct further research and explore additional resources to enhance their understanding of best practices in data management for their specific monitoring projects.

Summary of Best Practices for Data Collection, Management, and Reporting

To ensure the best practices for data collection, management, and reporting, it is important to be aware of common traps and issues that may arise during the process. Consider the following recommendations to enhance the quality and usability of your data:

1) **Plan for Long-Term Data Management:** Recognize that short-term data collection efforts may evolve into long-term projects or be integrated into regional databases. Therefore, it is crucial to adopt a systematic approach from the beginning, including clear data management protocols, consistent naming conventions, and well-structured folder organization (Millennium Ecosystem Assessment, 2005).
2) **Maintain Accurate and Complete Metadata:** Metadata is essential for understanding and interpreting data. Ensure that detailed information about sampling protocols, equipment used, data collection dates, and any other relevant context is recorded and associated with the dataset (Michener et al., 2012). Accurate metadata enables effective data management and enhances the value of the dataset over time. Additionally, keep detailed notes on data cleaning and analysis procedures to ensure transparency and reproducibility.

3) **Regularly Review and Update Data Management Practices:** Stay informed about emerging technologies, data storage methods, and best practices in data management. Regularly assess and update your data management processes to leverage advancements in technology and improve efficiency (Wood et al., 2013).
4) **Implement Quality Assurance/Quality Control Procedures:** Rigorous quality assurance and quality control (QA/QC) procedures are essential to ensure data accuracy, precision, and reliability. Regularly calibrate and maintain monitoring equipment, adhere to standardized protocols, and validate data through robust QA/QC procedures (Gray et al., 2014).
5) **Develop a Robust Data Management Plan:** Create a comprehensive data management plan that outlines procedures for data organization, storage, documentation, and quality control. Clearly define roles and responsibilities for data management, including protocols for data backup, security, version control, and the documentation of data cleaning and analysis (Michener et al., 2012).
6) **Select Appropriate Data Analysis Methods:** Choose appropriate statistical and analytical methods that align with the project's goals and objectives (Anderson & Thompson, 2004). Consider utilizing statistical software or data visualization tools to aid in data analysis and interpretation, enabling more robust and meaningful conclusions. Document the data analysis steps taken to provide transparency and facilitate reproducibility.
7) **Develop Effective Reporting and Communication Strategies:** Develop a reporting framework that includes regular reporting intervals and effective communication channels with project stakeholders and regulatory agencies (Millennium Ecosystem Assessment, 2005). Clearly present findings, conclusions, and recommendations in a format that is accessible and understandable to both technical and non-technical audiences. Include a description of the data cleaning and analysis methods used, along with any limitations or assumptions.
8) **Establish a Data Archiving and Accessibility Plan:** Develop a plan for long-term data archiving and accessibility to ensure the availability and usability of data for future analysis, research, and monitoring efforts (Whitlock et al., 2010). Consider utilizing appropriate data repositories or platforms that adhere to data sharing and accessibility standards. Include metadata components such as dataset description, data collection methods, variables measured, units of measurement, and data quality assessments.

By following these best practices, monitoring teams can avoid common pitfalls and ensure the accuracy, usability, and longevity of their collected data. It is important to recognize that data management is an ongoing process that requires continuous attention and adaptation to changing needs and technological advancements. For further information and resources on data management and best practices, we encourage you to explore the references provided in the document and conduct independent research tailored to your specific project's requirements and objectives.

1.4 How to Use/Read This Document

This document serves as a comprehensive guide for monitoring protocols in the context of Columbia River Estuary restoration and research. It is designed to provide researchers, field practitioners, and monitoring teams with essential information on data collection, management, and reporting across various ecological monitoring domains. To effectively navigate this document and make the most of its content, please consider the following:

1. **Organization of the document**: This document is structured into multiple chapters, each focusing on a specific monitoring method or topic. The chapters are organized in a logical

sequence to facilitate a step-by-step understanding of the monitoring process. Within each chapter, you will find detailed information and guidance for each method, including background, objectives, purpose, materials, methods, data management, and analysis.

2. **Introduction**: Begin by reading the introductory chapter, which provides a general overview of the importance of monitoring in restoration ecology and research. It introduces key concepts and considerations for developing a monitoring plan, including ecological factors beyond project boundaries.
3. **General considerations**: The introductory chapter (Section 1.3) includes valuable information on best practices for data collection, management, and reporting. It covers topics such as field protocols and safety measures, data management and record-keeping, and data analysis and reporting. These general considerations apply to all monitoring methods and serve as a foundation for ensuring data integrity and usability.
4. **Chapter-specific content**: Each subsequent chapter focuses on a specific monitoring method or topic. Here is a summary of the major monitoring protocol topics covered in the document:
    - C**hapter 2: Photo Points and UAV Imagery**: This chapter explores the use of photo points and unmanned aerial vehicle (UAV) photography for monitoring purposes. It provides guidance on setting up photo points, capturing UAV imagery, and utilizing orthomosaics.
    - **Chapter 3: Water Quality Monitoring**: This chapter delves into monitoring tidal wetland and tributary water quality, including water surface elevation, temperature, salinity, dissolved oxygen, and grab sampling. It covers data collection, deployment, retrieval, and data management considerations.
    - **Chapter 4: Marsh Surface Elevation Monitoring**: This chapter focuses on tracking changes in tidal wetland elevations, monitoring sediment accretion and erosion, and conducting channel cross-section and flow monitoring. It provides detailed methods and data management suggestions for each aspect.
    - **Chapter 5: Wetland Plant Community and Soil Conditions Monitoring**: This chapter addresses plant community monitoring, including species composition and mapping, tracking wetland primary production through aboveground plant biomass collection, and measuring soil conditions in the field and through lab analysis.
    - **Chapter 6: Macroinvertebrates**: This chapter explores various methods for sampling macroinvertebrates, including benthic cores, fall-out traps, neuston net tows, and zooplankton sampling. It covers data collection, analysis, and data management considerations.
    - **Chapter 7: Fish**: This chapter focuses on fish community monitoring, including data collection, analysis, and data management considerations. It also includes specific methods for otolith collection and analysis, fish lipid determination and condition factor assessment, and using PIT tag arrays.
    - **Chapter 8: Considerations for Data Management**: This chapter provides insights into various aspects of data management, including field data collection, metadata creation, data storage, data analysis, and the use of Tableau software for visualization and analysis.
5. **Note about Authorship**: This protocol document represents a synthesis of collaborative efforts and insights from a wide array of individuals and research partners under the auspices of the Lower Columbia Estuary Partnership. While the foundational framework was significantly informed by the original CEERP protocols document titled 'Protocols for Monitoring Habitat Restoration Projects in the Lower Columbia River and Estuary' by Roegner et al. (2009), this current document extends beyond these beginnings. Valuable contributions have also been integrated from April Silva's master's thesis (2020) and Sarah Kidd's dissertation (2017). Further,

this document has been enriched by research methods published annually in the LCEP's Action Effectiveness Monitoring Report (AEMR) and Ecosystem Monitoring Program (EMP) reports. These reports, authored and edited by researchers such as S. Rao, I. Edgar, S. Kidd, M. Schwartz, and others, have provided updated methodologies and insights that have been essential in shaping the comprehensive monitoring protocols presented here

6. **Authorship Organization:** Every chapter and section within this document is structured to function as an independent document, complete with its own authorship details. If a chapter's sections share identical authors and editors, their names appear at the chapter's commencement. However, for sections with distinct authorships, the relevant names are indicated at the start of each specific section.
7. **Citations**: Each section of this document includes specific authorship, editor, and citation notes. Please cite the respective authors and chapters when using or referencing specific sections. The suggested citation for the entire document is provided, along with a suggested citation format for each chapter.

By following the structure and content of this document, you will gain a comprehensive understanding of monitoring protocols and best practices. Each chapter provides detailed guidance, enabling you to apply the methods effectively and ensure the accuracy and usability of collected data. We encourage you to consult the chapter-specific content and references to tailor the monitoring protocols to your specific project's requirements and objectives.

Remember that monitoring is an ongoing process, and adapting to changing needs and advancements is crucial. Regularly reviewing the document, conducting independent research, and staying informed about emerging technologies and best practices will enhance the effectiveness and longevity of your monitoring efforts.

We, the Monitoring and Research Team at the Lower Columbia Estuary Partnership, have taken on the responsibility of authoring and editing this document, bringing together contributions from various experts in the field. As the editors, we have worked diligently to ensure the consistency, coherence, and technical accuracy of the content across all chapters. We are committed to providing comprehensive guidance and support for your monitoring endeavors in the Estuary.

We welcome your feedback and encourage you to engage with us regarding any clarifications or suggestions for improvement. Together, we aim to continually enhance and refine these monitoring protocols to advance our collective understanding and conservation efforts in the Lower Columbia River Estuary. Regular revisioning of this document will be done to encompass ongoing feedback from our regional partners and experts.

We hope that this document, titled "Protocols for Monitoring Juvenile Salmonid Habitats in the Lower Columbia River Estuary," serves as a valuable resource to support your monitoring endeavors in the Estuary.

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Photo Points and UAV Photography

2.1 Photo Points

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Background

Photo points can play a crucial role in any monitoring program and are collected through both our Ecosystem Monitoring Program, as well as the Action Effectiveness and Research Programs to supplement other monitoring efforts. These methodologies have evolved over time, with foundational concepts and techniques informed by past protocols such as those from LCEP 2007, Roegner et al. 2009, and the Oregon Watershed Enhancement Board's Photo Point Monitoring in 2021. These photographic records offer a robust and visual chronology of habitat transformations, allowing researchers to discern the long-term implications of restoration interventions.

Objective

Photo-point monitoring serves as a visual storytelling tool, capturing the journey of restoration projects from their inception to their post-implementation stages. This protocol aims to guide users in systematically documenting the time, location, and focal subjects in these photo points, ensuring consistency across varied monitoring initiatives.

While specific photographs capture nuances, like construction methods or the aftermath of significant environmental events, their real power lies in showcasing change over time. For instance, a series of photo points can visually narrate how a landscape responds to a restoration effort. The primary aim of these restoration projects is transformation, and photo points visually testify to this evolution, offering a tangible measure of a project's impact.

When setting up photo points, it's crucial to select sites where anticipated changes are most evident. For instance, if a project involves modifying a bridge, levee, or tide gate, the chosen photo points should offer a clear vantage point of these structures throughout the monitoring phase. Given the diverse elements within a single project, it's essential to represent each distinct feature with its dedicated photo point. Sometimes, capturing the full essence of a feature might require multiple photo points, for instance, needing both upstream and downstream views for a culvert modification.

It's also essential to consider the practicality and efficacy of these photo points. Factors like dense foliage, inadequate lighting, or obstructed views can hamper the photo's clarity and usefulness. Therefore, always opt for locations that offer clear, unobstructed views of the project's features. For continuity, including permanent landmarks in the frame can assist in replicating the exact framing in future shots, providing a consistent visual chronicle over the years.

Materials

- Camera or cell phone
- Compass
- Map of established photo points (digital .kmz file and/or printed)
- Drone/ Unmanned Aerial Vehicle (UAV) and associated accessories like ipad, remote controller, SD Card and extra batteries
- *Optional:* Sign or ID marker, copies of previously taken photos for reference
- PVC marker (optional)
- Mallet (optional)

Methods

Location Selection

Photo points should be implemented pre-restoration to establish baseline conditions. Locations are based on the visual change to be documented, areas where the change is predicted to occur (e.g., culvert removals, levee breaches, elevation modifications, replanting), and accessibility post-restoration. Each photo point should have a goal and objective, such as "track changes in the culvert at its opening to mainstem connect" or "observe plant community development in soil scrap down area." Having specific goals and objectives for each photo point will help with data interpretation over time, and this will also aid in the QA/QC of images post-collection. The number of photo points will depend on the size of the restoration site, specific restoration goals, and the level of effort and budget available to the monitoring organization. Based on these considerations, a map of photo points should be developed and used in the field. It is advisable to have a digital copy of the photo point map or a google earth file (.kmz) for easy navigation in the field (Figure 1).

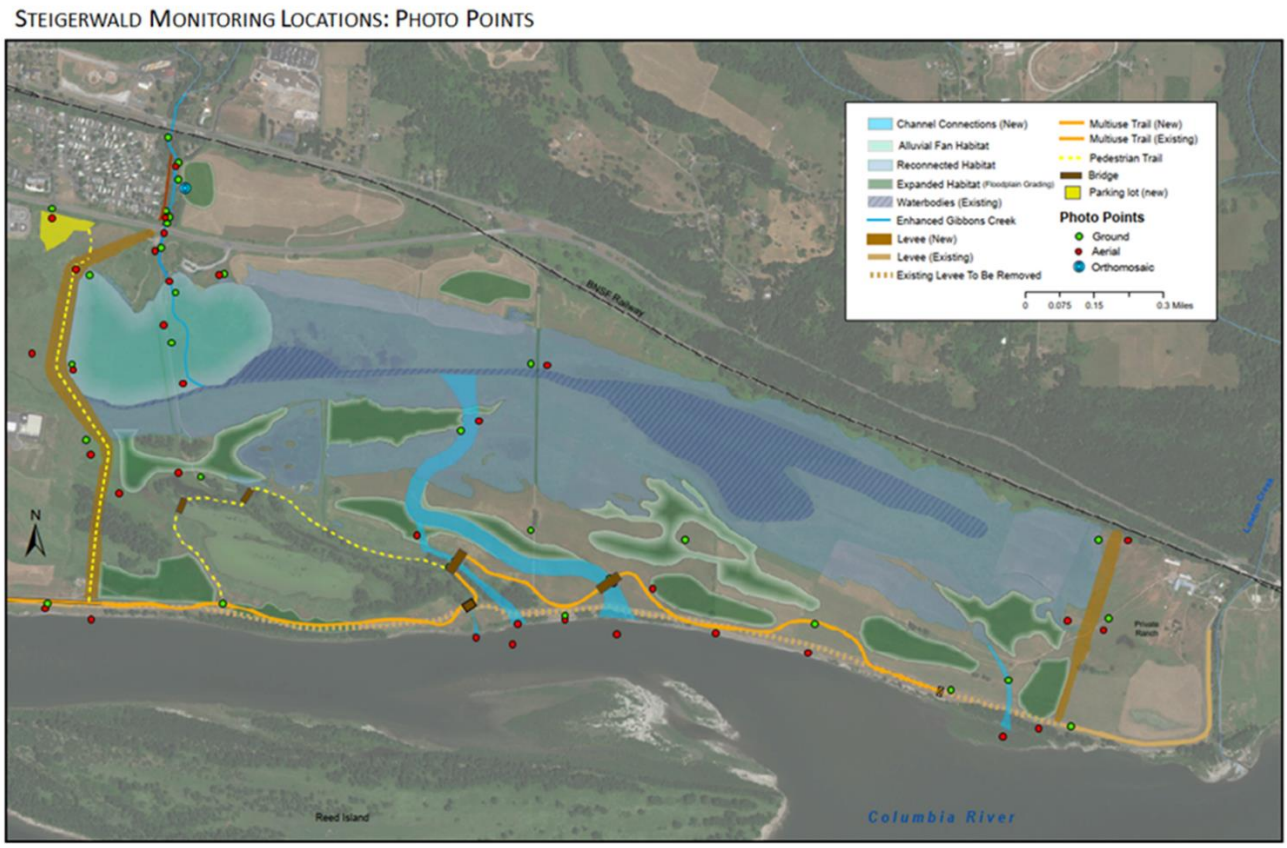

Figure 1: Map of ground and aerial photo points established at Steigerwald. Green dots represent ground photo points and red dots represent aerial/UAV photo points. Note that the network is established around significant restoration activities. In addition to these, ground photo points must also be included in areas with vegetation transects, sediment accretion benches, and at dataloggers.

Data Collection

Variability in photo monitoring greatly reduces with the establishment of permanent photo points, which are replicated over time. Here, we provide methods for ground and aerial photo points that can ensure efficient and accurate data collection.

Ground Photo points

In this section, we provide a brief summary of methods. For very detailed photo point method suggestions, see *LCEP 2007.*

Labels can be created for each photo point on any size piece of paper and included in the photo for records. Photos without visible IDs should be labeled electronic files to facilitate long-term data management; think about a new person taking over monitoring and how they would be able to recognize past data. It is recommended that an electronic record, perhaps in excel, be kept that includes the GPS coordinates, device used to take the picture, zoom level, direction, ID, personnel monitoring, and date. It is helpful to have a copy of the previous year's photo point when retaking photos in the field, either on paper or on a field computer or phone.

Figure 2. Examples of photo points taken with different devices immediately post-restoration (left) and several years post-restoration (right).

Data Management and Analysis

Data Management

Managing photo points and video media for long-term monitoring can present challenges. To ensure effective data management, it is crucial to create an organized and well-labeled filing system. In addition to writing directly on the images, this system can help streamline data organization and accessibility. As mentioned earlier, each photo point should have associated metadata, including GPS coordinates, time, date, project details, the person responsible for the photo, and a description of the photo point's intended observation and research question/objective. Saving these metadata in an excel spreadsheet within the folder containing the photo points can facilitate interpretation and future data collection for photo point monitoring.

For a more comprehensive and efficient data management system, it is recommended to explore available software options specifically designed for managing photo points and their metadata online. These software tools can provide enhanced functionalities such as automated metadata extraction, geospatial mapping, and data visualization, streamlining the management and analysis of photo point data.

Analysis

Photo points serve as valuable tools for visually documenting and illustrating the progress and changes observed at restoration or long-term monitoring sites. They play a critical role in communicating restoration results and outcomes effectively. One approach to analyzing photo point data is to include multiple side-by-side (timeseries) photos in reports or presentations. These photos can be paired with the technical monitoring data collected at the same location, when available, to provide a comprehensive understanding of the observed changes over time.

In addition to their role in visual documentation, photo point data can also contribute to model development and provide context for determining the need for more detailed and technical monitoring. By analyzing photo point data alongside other monitoring data, patterns, trends, and correlations can be identified, enabling better-informed decision-making and adaptive management strategies.

For more detailed information on the analysis of photo points and their integration with other monitoring approaches, refer to section 5.2. This section provides specific guidance on how photo points can be used in conjunction with other monitoring methods to enhance data analysis and interpretation.

References and Resources

The monitoring protocol can be found on monitoringmethods.org (Method ID821)

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2.2 UAV Photography and Orthomosaics

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Background

The Estuary Partnership's experience with Unmanned Aerial Vehicle (UAV) data collection and processing began with M. Schwartz from 2015 to 2019. In 2019, S. Rao collaborated with N. Elasmar to further develop UAV data collection and raw data processing protocols. Currently, S. Rao leads the UAV data collection efforts, while S. Kidd provides technical expertise in assessing the quality and application of these data for site-wide monitoring of plant community and hydrologic dynamics.

Objective

Aerial UAV photo points

Using a UAV to collect aerial images of a site has become much more cost effective and accessible over the last few years. We recommend all new restoration projects plan to have a suite of UAV images and videos collected in addition to standard photo points across a project - choosing where and when to take these images require all the same consideration and planning as ground images which you can find detailed in Section 2.1. Aerial UAV photo points can focus on varying project elements and capture much larger geographic scales as well as a much finer level of detail, capture infrared (and other non-visible) spectra for analyses, as well as produce site-wide digital surface models. Feature UAV photo points should focus on a large specific project element, such as a scrape down area or a channel enhancement zone.

Aerial UAV Mapping and Specialized Data Collection

UAVs can be equipped with various sensors, including multiple light spectra, LiDAR, magnetometers, and more, depending on the research questions. While this section emphasizes visible and infrared spectra, it is important to consider these methods for all UAV studies. Multispectral aerial photography enables site-wide vegetation mapping, digital surface model development for hydrology modeling, tracking channel development, and other valuable analyses. Additionally, thermal drones hold potential for monitoring surface water temperatures over time, and we are just starting to integrate this technology into our monitoring and research efforts, with ongoing updates on this as our methods develop.

The methods for UAV data collection, as outlined in this protocol, are designed to provide comprehensive and accurate data for a wide range of research questions and monitoring purposes. Researchers are encouraged to tailor their data collection approach based on the specific objectives of their study and the available UAV sensor options. For example, Kidd et al. (2022) utilized RGB and near-infrared sensors in their UAV analysis of vegetation communities at the Wallooskee restoration project at year three post-construction. Their analysis showcased changes in native and non-native plant communities, topography, hydrology, and salmonid access overtime following restoration efforts (see Figure 3). Detailed information on the data analysis methods for the UAV data processing and interpretation can be found in the 2022 and 2021 annual AEMR reports (Kidd et al. 2022 and 2021), which are valuable resources for researchers seeking to apply similar UAV-based monitoring and analysis methods in their own projects.

Another useful report to consider when planning a UAV mission and associated research questions for evaluating salmonid habitat is NOAA's Remote sensing of wetland restoration projects to benefit juvenile salmon: integrating LiDAR with hyperspectral imagery, published in the spring of 2023. This report holds valuable applications and lessons learned.

As researchers continue to explore the integration of various sensors and adapt their UAV data collection strategies, it is essential to ensure that the data collected are appropriate for addressing their research questions effectively. By following the guidelines presented in this protocol, researchers can maximize the utility and value of their UAV-based data collection efforts, contributing to improved ecological and environmental studies and facilitating informed decision-making in habitat monitoring and restoration projects.

Figure 3: Wallooskee Youngs Habitat Accessibility and Plant Community analysis.

Materials

- UAV certified pilot and observer
- All required permits and permissions
- UAV and Controller, optionally outfitted with a Sentera NIR Sensor
- iPad, Tablet, or phone compatible with the UAV and Controller
- UAV extra batteries
- Generator, car battery + inverter, or another method to recharge batteries (optional)
- Ground control points and tent stakes
- Spray paint (optional)
- RTK
- Datasheets
- Handheld camera (e.g., a cell phone camera)

Methods

The UAV data collection process involves several key steps that are essential for acquiring accurate and reliable geospatial information. Before initiating any flight, thorough pre-flight planning is crucial. This includes considering the integration of various sensors for specialized data collection, such as multispectral and thermal imaging, based on the specific research questions at hand. Regularly reviewing and updating UAV protocols and procedures is also vital, given the rapid advancements in technology and the importance of making informed decisions for successful missions. Researchers must ensure all necessary permissions and approvals, including those from the Federal Aviation Administration and other relevant authorities, are obtained before planning the mission. Adherence to safety guidelines is paramount, with direct visual contact with the drone during flights being a standard practice. Furthermore, careful consideration of weather conditions is essential to avoid flying in unfavorable weather, such as rain or windy conditions, which could impact data quality. To optimize data collection, selecting flight times that coincide with peak low tide events and flying early in the morning, especially in tidal sites, is recommended. The number of polygons per flight should be determined based on factors like available batteries, flight height, and post-processing computer capacity, with a general guideline of not exceeding 100 acres per polygon. Additionally, planning the number and locations of ground control points (GCPs) is vital for precise georeferencing of UAV imagery. GCPs should be set out in visible locations, and their positions should be accurately recorded using an RTK-GPS. Capturing photos of the GCPs from multiple directions and recording vegetation and ground cover data in field datasheets ensures comprehensive post-processing vegetation classification. Ultimately, careful planning, adherence to best practices, and meticulous data management lay the foundation for successful UAV data collection and analysis.

STEIGERWALD UAV GROUND CONTROL POINT DISTRIBUTION: CO-LOCATED WITH GROUND ELEVATION SURVEY AND VEGETATION OBSERVATIONS

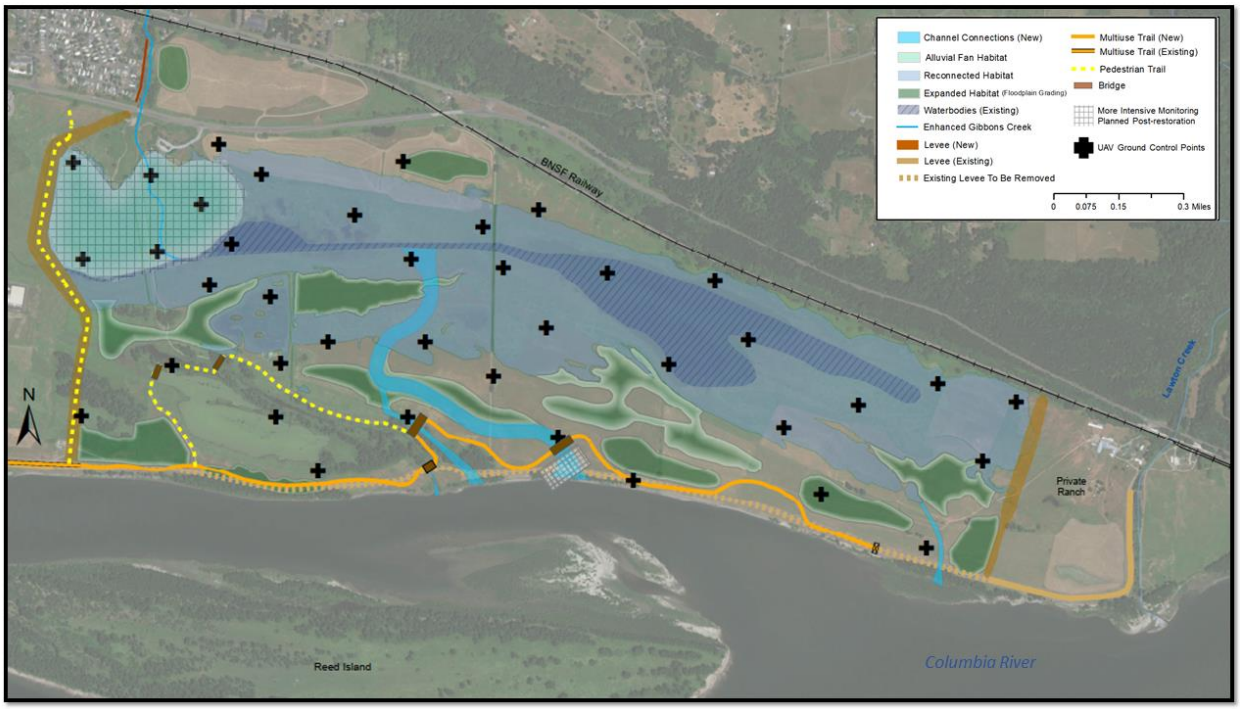

Figure 4: Illustrative Map of Steigerwald Ground Control Points

Pre-flight Planning:

- Consider integrating various sensors for specialized data collection, such as multispectral and thermal imaging. Select the optimal sensor combination to address specific research questions effectively.
- Frequently review and update UAV protocols and procedures as technology is advancing rapidly. Informed decisions lead to the most successful UAV missions. Request permission to fly from the nearby Federal Aviation Administration office, if required. Additionally, seek any other permissions required, such as special use permits for federal refuge property. Ensure all laws and regulations are met before planning the mission.
- Consider safety guidelines and ensure direct visual contact with the drone during flights.
- Check the weather forecast before departing for the field site, avoiding flying in rainy or windy conditions.
- Select flight times and weather conditions that optimize data collection, aiming to fly early in the morning and during a peak low tide event, especially in tidal sites where wind speed may increase throughout the day. Noon or mid-day at non-tidal sites is recommended to reduce shadows.
- Determine the number of polygons needed for the flight based on the available batteries, flight height, and post-processing computer capacity. Generally, a single polygon should not exceed 100 acres.
- Decide on the number of ground control points (GCP) needed and create a KMZ file with the approximate GCP locations, covering a wide range of elevations and geographic features at the site.
- Plan to use ground control points for accurate and precise georeferencing of UAV imagery.

- Plan to record metadata, including GPS coordinates and time, for each UAV photo.

Ground Control Points:

- At the site, navigate to the pre-planned points where the GCPs should be placed.
- Set out GCPs in locations clearly visible in UAV imagery. In dense vegetation, push down vegetation to create level ground for GCP placement.
- Secure GCPs with tent stakes and label each GCP using a waterproof marker or water-based spray paint, indicating the GCP number.
- Record GCP locations (Lat, Long, Elevation) using an RTK-GPS. Preferred coordinate systems are NAD83 UTM Zone 10N or WGS84.
- Capture photos of the GCPs in all four directions (North, South, East, and West), showing surrounding vegetation and site features for post-processing vegetation classification.
- Record dominant vegetation/bare ground around and under each GCP in a field datasheet, noting the GCP number and percentage of vegetation cover.
- Compile GCP photos and datasheets into a single cloud database/folder.
- Include RTK data with UAV imagery for processing in Pix4D.
- (Optional) Recover GCPs after the flight if using vinyl or non-biodegradable markers.

Flying:

- Carry batteries, drone, GCPs, RTK, and other necessary equipment to a central location inside the site.
- Deploy GCPs while navigating around the site and surveying them.
- Prepare the drone for flight.
- Use the DJI or drone-specific app and the Pix4D flight planner, or other flight planning apps to create flight polygons based on pre-flight planning.
- Launch the drone, maintaining direct eye contact, and follow the flight plan.
- When the battery reaches 20%, bring the drone back to the launch station and exchange the battery with a fresh one. Recharge used batteries if needed.
- Repeat steps 5 and 6 until all polygons are completed.
- After flying the polygons, take oblique photos, flyover videos, and additional aerial photos as desired.
- Pack up the drone, recover GCPs (if needed), and leave the site.
- Download and back-up data from the SD card shortly after returning from the field.

Processing:

At the Estuary Partnership (LCEP), we process our RGB (Red, Green, Blue) and near-infrared UAV data using Pix4D Mapper, a powerful photogrammetry software that transforms raw aerial imagery into valuable geospatial data. It is important to note that various software options are available on the market, and researchers can choose the one that best suits their specific needs and objectives.

LCEP's Detailed Pix4D Mapper Protocol (Rao et al. 2022): the Protocols for Drone Image Processing

For those interested in our specific Pix4D Mapper workflow, we have developed a comprehensive protocol that guides our data processing from start to finish. This detailed protocol ensures accurate and reliable results for our RGB and near-infrared imagery processing.

Image Upload and Initial Processing:

- ***a.*** Organize and transfer all UAV images from the SD card to your computer.
- ***b.*** Launch Pix4D Mapper and create a new project.
- ***c.*** Import the UAV images into the project, select the appropriate template and begin the initial processing in Pix4D.
- ***d.*** Check the image alignment and calibration before this stage to ensure all images are properly matched and oriented.

Ground Control Points (GCPs) and Quality Check:

- ***a.*** Input the GPS coordinates of the ground control points (GCPs) collected in the field.
- ***b.*** Pix4D will utilize the GCPs to enhance the georeferencing accuracy of the orthomosaic and models.
- ***c.*** Perform a quality check to verify the accuracy of the GCPs' georeferencing.

Point Cloud and Digital Surface Model (DSM) Generation:

- ***a.*** Pix4D will create a 3D point cloud of the survey area based on the aligned images.
- ***b.*** Use the point cloud to generate a high-resolution Digital Surface Model (DSM) of the site, providing information on elevation variations.

Orthomosaic Generation:

- ***a.*** Utilize the aligned images and point cloud to create a seamless and georeferenced orthomosaic of the survey area.
- ***b.*** The orthomosaic serves as an accurate representation of the site's surface, suitable for various analyses and measurements.

Data Analysis and Visualization:

- ***a.*** Analyze the orthomosaic, point cloud, and DSM to identify changes, patterns, and features of interest.
- ***b.*** Visualize the processed data in Pix4D Mapper or other GIS software for further analysis and interpretation.

Exporting and Sharing Results:

- ***a.*** Export the final orthomosaic, DSM, and point cloud in suitable formats for use in GIS and other software.
- ***b.*** Share the processed data and results with project stakeholders, collaborators, and research teams for further analysis and communication.

Quality Assurance and Control:

- ***a.*** Perform regular quality assurance checks on the processed data to ensure accuracy and reliability.
- ***b.*** Validate the results with field observations and ground-truthing, if possible, to verify the accuracy of the orthomosaic and models.

Please note that the Pix4D Mapper workflow described here is tailored to our specific needs for processing RGB and near-infrared imagery. Depending on your research objectives and data requirements, you may need to adapt and modify these steps or explore additional processing options, such as incorporating specialized analyses for multispectral data or 3D modeling. It is crucial to stay informed about advancements in UAV and photogrammetry technologies and regularly update and optimize your processing workflow for the best possible results.

By following this detailed Pix4D Mapper protocol, researchers can confidently generate accurate and valuable geospatial data, supporting informed decision-making in habitat restoration and conservation projects.

Data Management and Analysis

During data analysis and management, several best practices should be considered to optimize the handling of UAV data. Firstly, researchers should carefully consider the resolution and size of data products, such as orthomosaics and point clouds, to avoid unnecessarily large data files that may become challenging to manage, store, and share (Herrera et al. 2017). Secondly, regular backups of all UAV data, including raw images, processed products, and intermediate files, should be performed to prevent data loss and ensure data availability. Additionally, each dataset should have comprehensive metadata, including GPS coordinates, timestamps, flight parameters, and ground control point information, which is crucial for data interpretation and sharing (Herrera et al. 2017). To facilitate collaboration and data exchange, consider sharing UAV data online through secure cloud-based platforms or data repositories (Büyüksalih et al. 2017). In cases where online sharing is not feasible, establish a system for exchanging data through physical media such as external hard drives or USB drives.

Quality Assurance/Quality Control (QA/QC) procedures should be implemented to verify the accuracy and reliability of UAV data and products (Büyüksalih et al. 2017). Ground truthing, where feasible, can further validate data accuracy by comparing UAV observations with field measurements (Herrera et al. 2017). Integrating UAV data with other relevant datasets, such as GIS layers or remote sensing data, provides a comprehensive view of the study area and enables broader analyses (Büyüksalih et al. 2017). Cross-referencing UAV data with ground-based monitoring data or remote sensing datasets can offer additional insights into ecosystem dynamics and changes over time (Herrera et al. 2017).

Long-term data archiving is essential to ensure that UAV datasets remain accessible and usable for future research or monitoring efforts (Büyüksalih et al. 2017). Researchers should also utilize specialized software or GIS tools to analyze UAV data, such as conducting vegetation mapping, change detection, and hydrological analyses, within the context of the research objectives and project goals to draw meaningful conclusions (Kidd et al. 2023, 2022, 2020). Developing a comprehensive data management plan at the beginning of the project and regularly updating it based on challenges and advancements will help maintain effective data management practices throughout the project (Büyüksalih et al. 2017).

By adhering to these data management and analysis best practices, researchers can efficiently handle UAV data, ensuring its accuracy, security, and usability for informed decision-making in habitat restoration and environmental monitoring projects.

References and Resources

The monitoring protocol can be found on monitoringmethods.org (Method ID821)

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3. Water Quality Monitoring

3.1 Tidal Wetland Water Surface Elevation, Temperature, Salinity, and Dissolved Oxygen Monitoring

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Background

Tidal wetlands are dynamic ecosystems, influenced by a myriad of environmental variables, including water surface elevation, temperature, salinity, and dissolved oxygen levels. Understanding these parameters is pivotal, particularly in the context of restoration efforts, as they can drastically influence vegetation dynamics, sediment accretion, and overall ecosystem health.

At the Lower Columbia Estuary Partnership (LCEP), we recognize the critical nature of these factors and have incorporated them into our Ecosystem Monitoring Program (EMP) and Action Effectiveness and Research Programs (AEMR). These programs aim to track the ecological health of tidal wetlands, identify changes post-restoration, and guide future conservation strategies. By using ONSET dataloggers, we can capture real-time data on water surface elevation, temperature, salinity, conductivity, and dissolved oxygen. This comprehensive monitoring approach allows us to grasp the intricate tidal connections at restored sites and discern the consequential impacts on vegetation communities and sediment dynamics.

Our current methodologies are not developed in isolation; they are built upon a foundation of previous research and protocols. Notably, our techniques are informed and updated from seminal works such as those presented by Kidd et al. in 2018 and Roegner et al. in 2009. By integrating historical knowledge, LCEP strives to offer the most accurate and actionable insights into tidal wetland ecosystems.

Objective

Water surface elevation data, which can also serve as depth data, and temperature are both potentially limiting factors for juvenile salmon. Tidal wetland processes that are hydrologically driven, for example, the flux of organic materials, can be adversely impacted by water levels relative to land elevations. Increasing natural channel morphology is expected to increase habitat opportunity and prevent stranding, while tidal exchange can provide colder water input during incoming tides. Understanding the hydrology of a site is critical for all analyses conducted.

Basic questions that can be asked of these data include analyzing and comparing the depth, duration, and frequency of flooding across a site pre- and post- restoration to evaluate the success of tidal reconnection. Additionally, evaluating how water temperatures and depths have changed across a site pre-and post-restoration can provide insight to how restoration actions have increased salmonid habitat opportunity in the channel or even across the floodplain - depending on the hydrology of a site and its complexity.

3.1.1 Preparing for Water Surface Elevation, Temperature, Salinity, and Dissolved Oxygen Monitoring

Materials

T-post (6 ft)
PVC and cap (2 in or 3 in)
Mallet or post pounder
Hose clamps
Screwdriver (flat head)
Drill w/ large bit
Metal cable or heavy-duty string
U bolts
Screwdriver and/or wrench

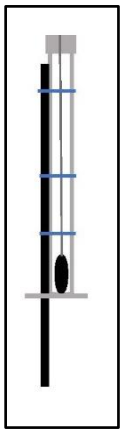


Figure 5. Data logger housing design.

A few critical things need to be included when designing the logger housing:

- Consider the site-specific conditions including water depth, water velocity, substrate type, visibility and potential for vandalism or theft.
- T-post needs to be sunk two to three feet into the substrate, while also tall enough to be accessed at high water (ideally loggers are switched out every six months)
- Account for boating traffic and large woody debris damage to the housing
- Do not have the housing sunk into or too near the substrate as it could sediment in
- Location should be representative of overall stream conditions, not placed in a scour hole where depth and temperature may be different than overall channel
- Data logger should be accessible every six months, plan its height accordingly

Methods

Location Selection

First, define the project goals for collecting the water surface elevation data to help determine the number and location of data loggers for monitoring. For a restoration project this might entail identifying which locations on the site are expected to experience a significant shift in flooding (timing and/or duration) pre- and post-project construction. You will also want to consider how easy it will be to access these locations pre-/post-restoration. Data loggers should be placed in locations expected to experience significant hydrological changes and in a location that can be easily monitored both before and after construction. If data loggers must be removed during construction, they will need to be relocated in approximately the same place after construction is completed for comparable data to be collected. A control or reference logger should be placed in a main channel outside of the site, for the duration of the pre and post project monitoring. This control logger data can then be used to evaluate the effectiveness of the restoration project at restoring hydrologic reconnection.

Control or reference data loggers are critical in assessing the impacts of annual climate variations. Foe example, the Dibblee Point Restoration Project experienced one of the hottest years on record (2015) one-year post-restoration. Without a mainstem control data logger, the data would have suggested that the site was experiencing increased water temperatures post-restoration, making it look like the restoration work resulted in degraded water quality conditions. Comparing the mainstem control data logger for one-year pre and one-year post demonstrated an overall change in water quality conditions,

providing substantive evidence that increased temperatures were not the result of restoration but instead resulted from dynamic environmental conditions.

Data loggers should be placed as deep as possible in a ditch or channel to avoid complete exposure to the air. This can be tricky for tidal locations, if possible, place the logger below the low tide elevation. Frequently exposed (no longer under water) data loggers generate incomplete data sets and are less accurate than data loggers which remain underwater during the duration of the sampling period. Additionally, if data loggers are exposed during the winter, there is a chance the logger will freeze resulting in data gaps and broken equipment. If data logger exposure is a potential issue, consider also deploying a groundwater well to track above and below ground water fluctuations.

If available, an additional WSE data logger should be deployed to collect ambient air temperature and pressure data to correct and obtain depth data from the submerged data loggers. This data logger should be deployed in a location that is easy to access as you are leaving a site and will not get flooded (such as on a nearby tree branch or fence post) – as you will want to pull this logger after collecting the others at the site to maximize the amount of data you obtained during the sampling period. Air pressure and temperature data loggers need to be shielded from direct solar exposure. The maximum distance a barometric logger, or data source (NOAA), should be from the water level logger is five miles (Onset 2015).

Selecting the number of data loggers

The number of data loggers placed on a site should depend on the number of locations where significant change is expected (post-restoration), the overall budget, staff constraints, and accessibility of the site and logger locations. Monitoring areas that are not expected to change can also be informative in terms of collecting baseline hydrologic data for modeling and a more extensive restoration outcome analysis. At a minimum one data logger should be located in the main channel (or ditch pre-restoration) of a site and in the adjoining stream/river that the site is going to be re-connected with.

Building the Housing

For tidal wetland sites t-posts between six and eight feet are recommended, with three-inch PVC pipes and PVC caps. The PVC cap has two holes drilled through it, while the PVC tube has holes drilled throughout its length to allow ample water flow and exchange. The PVC does not need to be any certain length; simply long enough to protect the data logger and be accessible for deployment and retrieval. A metal cable is attached to the cap through the two holes and secured on the inside with a U-bolt. A second U-bolt is used to attach the metal cable to the data logger cap. Heavy duty string can also be used but generally is not as secure. A combination of hose clamps and heavy-duty zip-ties are used to attach the PVC to the pole once it had been pounded into the substrate. Hose clamps can be tightened securely but are prone to rust, while zip-ties are more difficult to tighten sufficiently, and generally need to be re-tightened, but do not rust.

The tip of the data logger must be surveyed in to get X, Y, and Z data (Figure 6). The most accurate way to do this is to install a cross bar to the bottom of the PVC, with the tip of the probe resting lightly on it;

this can also prevent the logger from being lost if the string cable breaks. The other option is to RTK the top of the housing and subtract the length from the top of the housing to the sensor from the RTK elevation. QA/QC measurement will also be taken from the crossbar. PVC cut lengthwise (although tricky) allows for surveying equipment to rest in the groove, facilitating surveying and QA/QC measurements.

Figure 6. Metal cable and U-bolt assembly on data logger.

Before and After Deployment QA/QC Steps

Before deployment, the data loggers should always be checked for accuracy, especially if one wishes to submit any collected data to ODEQ, WEQ, or another entity.

QA/QC for WSE and Temp

The following QA/QC method can be used to check both water level and temperature accuracy. A temperature calibration check requires the use of an external thermometer, preferably one that is NIST certified (most YSI probes will work for this). If your project goals include creating thermal refugia or require water temperature monitoring, you should conduct a full temp calibration following Oregon DEQ protocols[1] or the Washington Department of Ecology protocols[2]. The below protocols outline an approach that aims to meet the requirements of both the State of Oregon and Washington when all three water bath temperatures are evaluated. This should be conducted before and after a data logger deployment.

(1 Oregon Plan for Salmon and Watersheds, Water Quality Monitoring Guidebook, Temperature Protocols Chapter 6: http://docs.streamnetlibrary.org/Protocols/021.pdf)
(2 Washington Department of Ecology Quality Assurance Monitoring Plan: Continuous Monitoring for Oxygen, Temperature, pH, and Conductivity in Statewide Rivers and Streams https://fortress.wa.gov/ecy/publications/summarypages/0903122.html)

Calibration should be done in an office, lab, or other indoor facility prior to deploying data loggers. First deploy data loggers to collect data at one-minute intervals, also concurrently deploy a data logger of known accuracy to collect ambient air pressure data at one-minute intervals. Fill a cooler with water and add the loggers, water should be at least 20 cm above the data loggers. Make note of the time, temperature, water depth above the data loggers and let loggers sit in the water undisturbed for 20 minutes, or until the temperature measurements with the NIST thermometer stabilize. It is important to give the data loggers adequate time to equilibrate to the water bath temperatures. The goal of a temperature calibration is to get 10 continuous – 1 minute interval temperature measurements with the NIST thermometer that are comparable to the temperatures.

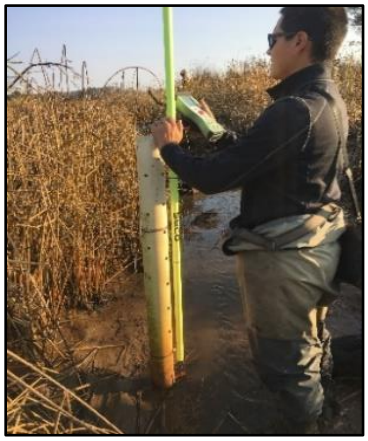


Figure 8. Surveying data logger elevation from crossbar.

Figure 8. Example of data logger housing used in the field.

QA/QC for Salinity and Dissolved Oxygen

Calibration should be done in an office, lab, or other indoor facility prior to deploying data loggers. First deploy data loggers to collect data at one-minute intervals. Place loggers in a covered water bath for an hour. Also use an external YSI to record the salinity and Dissolved Oxygen of the water bath. Once the hour is up, compare the datalogger records to the YSI readings. The readings should be within ±0.5 units.

3.1.2 Deployment, Retrieval, and Downloading Water Surface Elevation, Temperature, Salinity, and Dissolved Oxygen Data Loggers

A logger should either be replaced on an annual basis or downloaded once per month. While it is recommended to fully swap the logger and have a cache of extra loggers, it can be an increased monetary cost. Swapping loggers helps reduce the potential for logger failure and data loss and will eliminate the need for additional field expeditions to replace a faulty logger.

Materials

- New Logger or shuttle
- Spare hose clamps
- Zip ties
- Screwdriver (flat head) and/or socket screwdriver (sized for hose clamp)
- Spare Metal cable or heavy-duty string
- Wire cutter
- Wrench
- Ruler
- Rite-In-The-Rain notebook
- Pencil
- YSI

Methods

Deployment and Retrieval

Launch and place logger in a bucket of water a few days prior to deploying. Note the time, temp, and depth of the water for later use as a reference water level and record it in a data log. Once in the field, RTK the top of the housing prior to any modifications to acquire the sensor elevation. Remove the logger and record the serial number of both the old logger and the new logger. Ensure that the cord, zip ties, and hose clamps are in good working order and replace if they are not. Replace the logger and record everything mentioned in Table 1. Return to the office and repeat the bucket calibration checks.

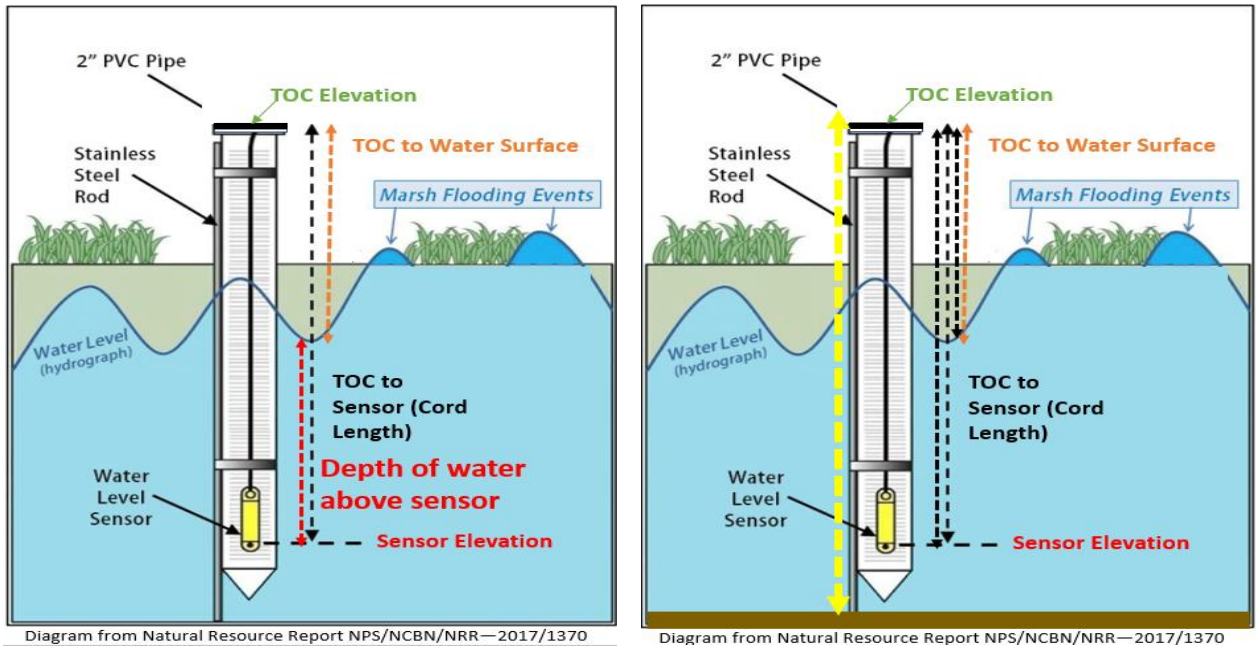


Figure 9: Measurements to record while in the field

Table 1: Metrics to record when deploying, retrieving, or downloading a logger.

Item to record	Additional Descriptions
Site Name:	*This is the name of the site.*
Logger Location:	*This is the precise logger location*
Date:	*Date of deployment*
Time:	*Time of swap*
Logger Serial Number of Placed:	*Serial number of new logger (this one is getting deployed into the field)*
Logger Serial Number of Removed:	*Serial number of old logger (this one is leaving the field)*
Logger Type (WSE, Cond, etc):	*Type of logger*
Collection interval (minutes):	*Collection interval*
Top of cap to logger sensor – (Cord length; cm):	*Length of cord*
Water surface elevation to top of cap (cm):	*Water surface elevation to Top of Cap*
Ground to water surface elevation (cm):	*Ground to water surface*
YSI Temp (°C):	*Water temp*

YSI Conductivity (µS):	*Conductivity*
YSI Salinity (ppt):	*Salinity*
YSI DO Percent Saturation (%):	*DO Percent Saturation*
YSI DO Concentration (mg/L):	*DO Concentration*
YSI pH:	*Water PH*
Notes about logger condition, location, etc	*Notes about deployment*

Processing Data

These steps are borrowed from the 2018 Best Practices–A Quick Guide to HOBOware Data Processing and Management and the 2020 *Data Logger Processing Protocols* document. Refer to them for additional steps and guidance.

Once the data logger has been retrieved from the site and post- deployment water depth measurements have been made, the data can be processed and used to evaluate the conditions on the site. Below are some tips for processing the data in HOBOware.

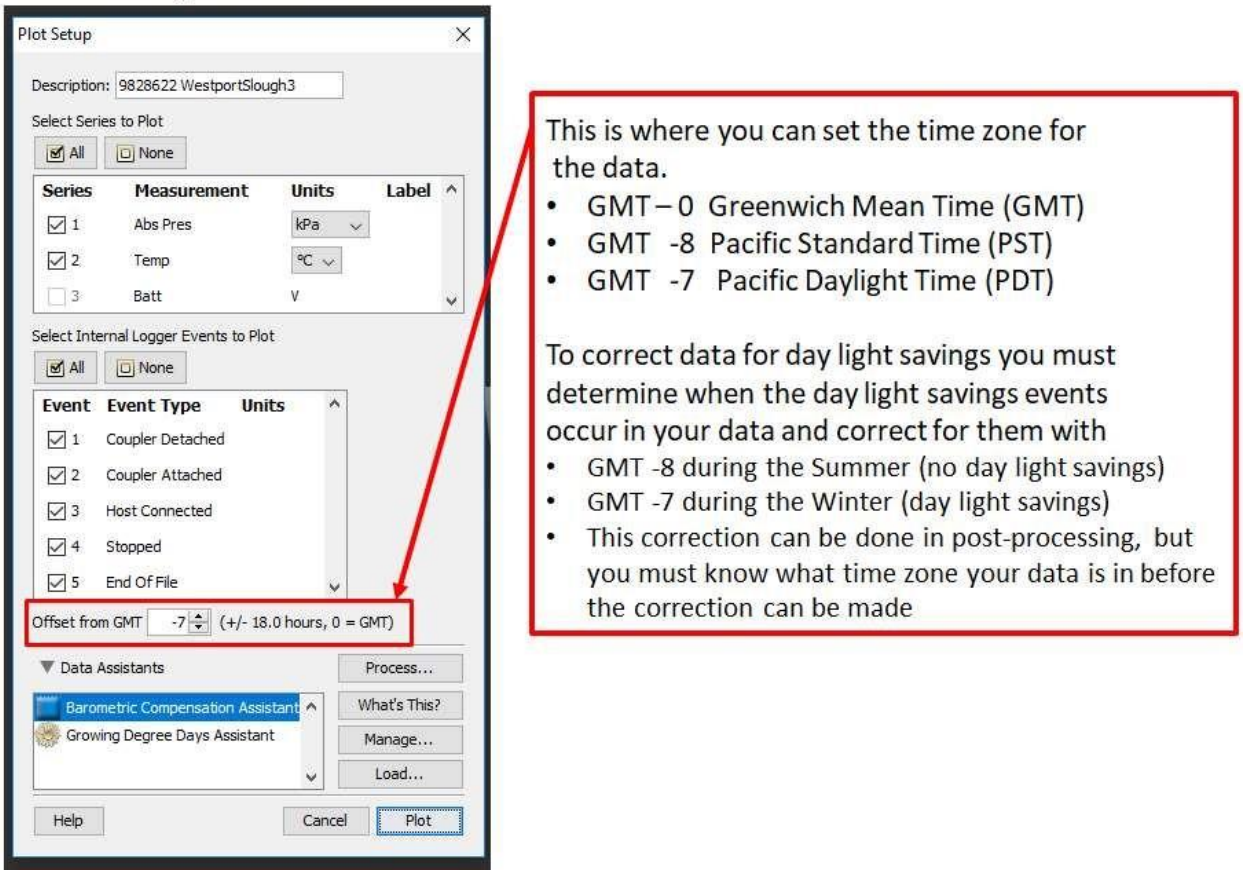
1. Understanding GMT and Correcting for Daylight Savings

   It is best practice to always be aware of which time zone the data logger is collecting in. HOBOware does not automatically correct for daylight savings. Additionally, the data logger will be launched in whichever time zone your computer clock is in at the time of deployment unless it is adjusted manually. This means if you deploy your data logger in the summer (Daylight Savings Time) and then retrieve your data logger in the winter (Standard Time) your data will be read out in Daylight Savings Time, all time stamps after the fall time boundary (such as November 4 at 2 am) will be an hour off (one hour behind) because HOBOware does not adjust for shifts between Daylight Savings and Standard Time. This adjustment will need to be done manually in Excel, once exported from HOBOware. Correcting data for the end or beginning of daylight savings time can cause issues with time series data analysis because it involves deleting or duplicating a date and time when the data crosses a time boundary. Specifically, when daylight saving times begins clocks are moved forward one hour, meaning the 2 am date time on that day is deleted, while when daylight savings time ends the clocks go back one hour, meaning the 2 am time stamp is repeated. To avoid issues with duplicate and deleted time stamps data should be collected and stored in Standard Time, in the Pacific Time Zone this is GMT-8.

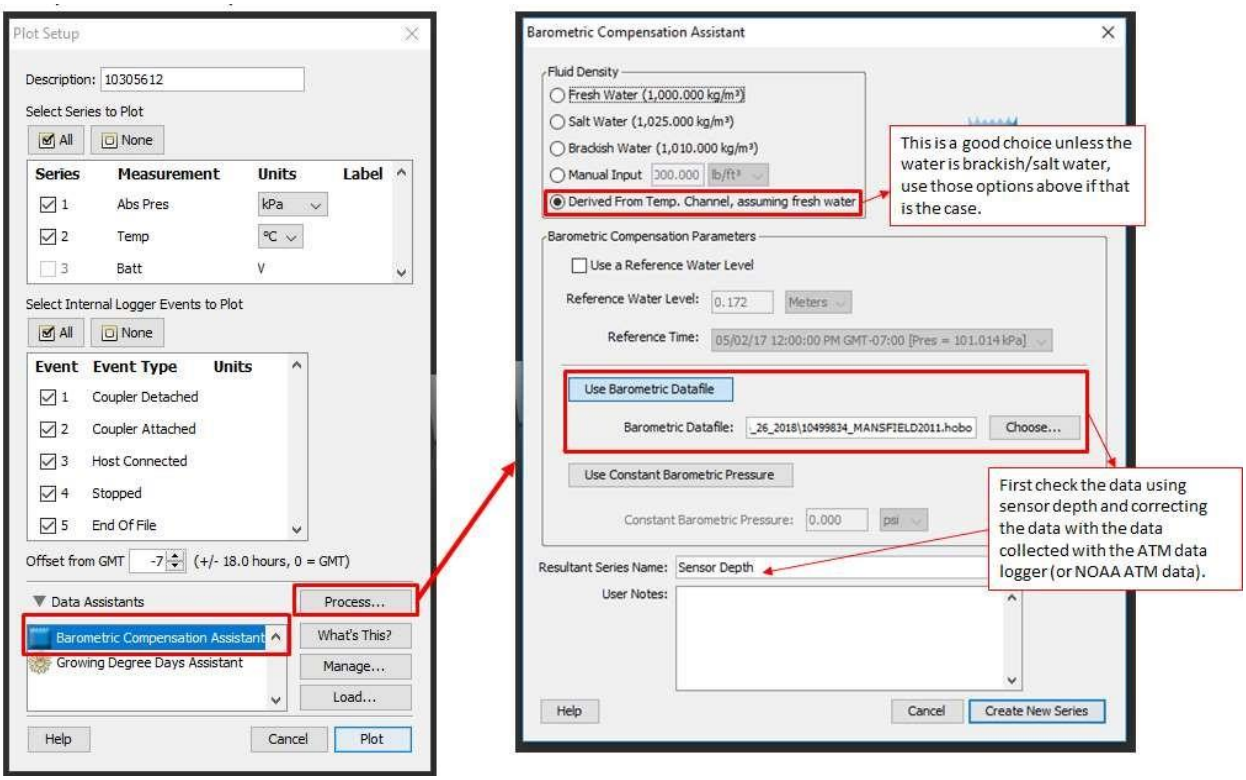
   It is particularly important to understand how these shifts between daylight savings ending and beginning impact your date and time stamps when trying to compare your reference water levels and temperatures collected to your data logger data. For example, if you are collecting all your data in Standard Time (i.e., GMT-8) you will need to make a small adjustment to your reference measurement date and time stamps collected during daylight savings time (i.e., Mar – Nov, see an annual daylight savings table for exact dates) so that the reference measurement time and dates match the loggers time and dates. To shift a daylight savings time stamp (i.e., GMT-7) to a standard time stamp (i.e., GMT-8) you only need to add one hour.

Lastly, understanding the time zone your data is collected in is critical for comparing time series data sets such as multiple loggers to one another or to a gage station, and when correcting your data with barometric data. It is essential to make sure all data sets are in the same time zone for meaningful analyses to be conducted.

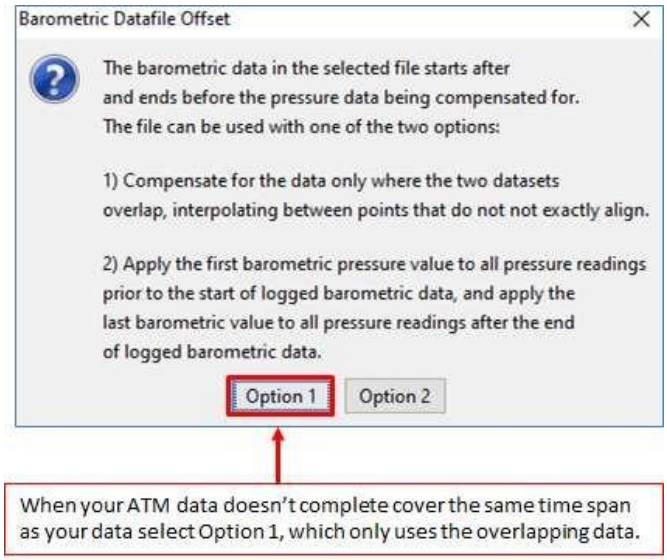
GMT: Setting the time zone



2. Using the Barometric Compensation Assistant, make sure you have your ATM data handy; it will need to overlap your sampling to work properly. The first step is to select the Barometric Compensation Assistant and then within this tool select the correct fluid density. If working with freshwater or oligohaline data using the "Derived From Temp" option works well.



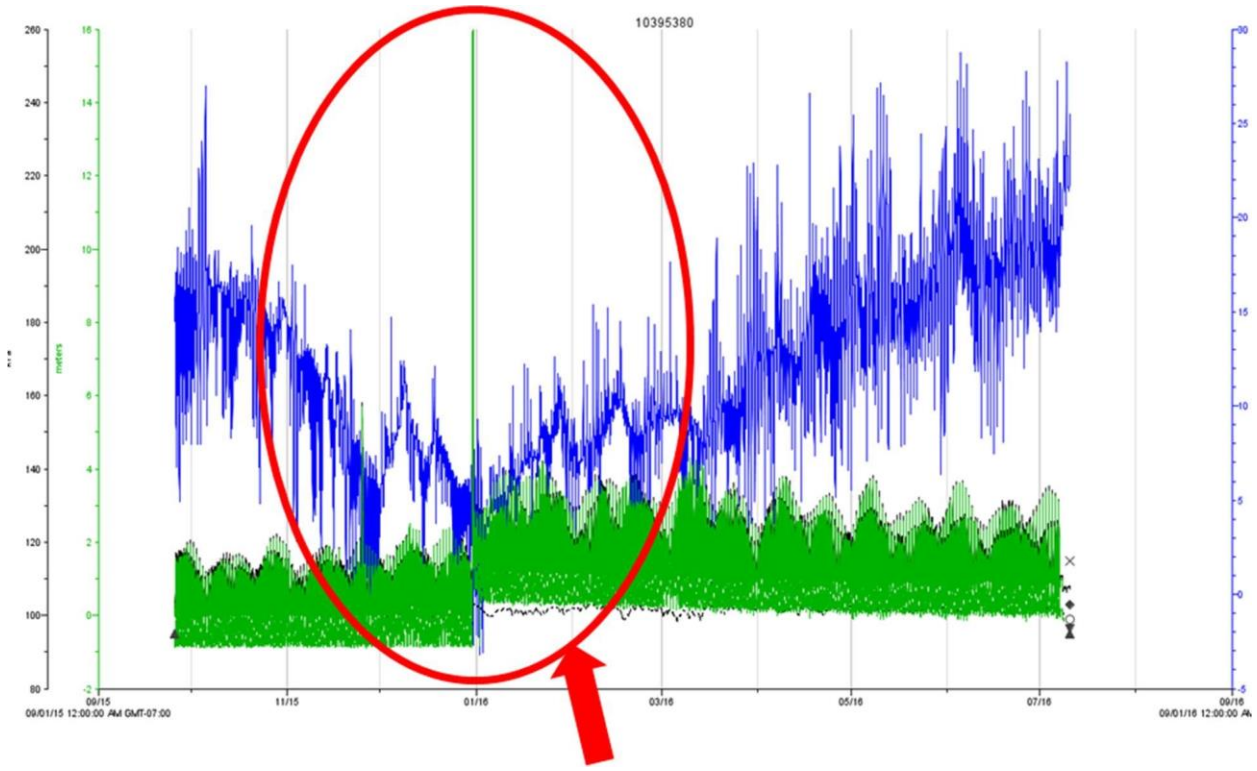
- Then select the ATM data file to have the data corrected for Sensor Depth, this process does NOT require a reference water level and can be used to evaluate how the data logger is functioning by checking sensor depth results with the calibration sensor depth data collected directly in the field.



3. Trouble shooting data issues

   - If the sensor depth data is off by more than ± 5 cm of your field or office reference measurements, you may need to correct your data with a reference water level (instead of just using the derived sensor depth). This is easily done by going back into the Barometric Compensation Assistant and entering a reference water level (in meters) instead of selecting sensor depth (Figure 6). It is important to have multiple reference measurements during the deployment, so when you use one to correct the data and have others to check against and evaluate the accuracy of the correction.

   - During winter deployments data loggers can freeze and this can cause a systemic error to occur with the sensor depth calculations (see below figure for reference). If this occurs, the data will need to be corrected multiple times (before and after the error occurs) using deployment and retrieval reference water levels. Then the two sets of corrected data can be joined in excel during post-processing.



4. Export data from HOBOware into MS excel as a workbook. During the HOBOware session, you should check your resulting depth data against your reference water level measurements to confirm it is accurate. An image of the resulting table is included below

A	B	C	D
Plot Title: 20149615			
#	Date Time, GMT-07:00	Temp, °C (LGR S/N: 20149615, SEN S/N: 20149615)	Sensor Depth, meters (LGR S/N: 20149615)
1	7/9/2018 16:45	16.808	-0.011
2	7/9/2018 17:00	22.621	0.162
3	7/9/2018 17:15	24.448	0.158
4	7/9/2018 17:30	24.351	0.157
5	7/9/2018 17:45	24.158	0.155
6	7/9/2018 18:00	23.966	0.154
7	7/9/2018 18:15	23.869	0.153
8	7/9/2018 18:30	23.773	0.153
9	7/9/2018 18:45	23.677	0.15
10	7/9/2018 19:00	23.484	0.151

Figure 10: Datalogger exported excel raw data

5. Create a duplicate excel sheet in workbook for editing (in example workbook this is labeled "RawTrimEditing")

6. Trim the sensor depth data to the correct deployment start and end times based on a deployment log. A deployment log is essentially an excel sheet that has information of the site, location of the loggers, date and time of installation, data collection interval, downloads, repairs and removal or reinstallation.

An example is shown below for better understanding.

A16 : MCNA

	A	B	C	D	E	F	G	H
1	Site	Location	Date	Time	Removed/ Downloaded/ Placed	Serial Number	Logger Type	Collection Interval
14	MCNA	MC2- Outside NWCS	6/24/2019	9:36	Removed	20502398	DO	30
15	MCNA	MC2- Outside NWCS	12/13/2018	9:04	Placed	NEED #	Do	30
16	MCNA	MCNA1- N channel	12/13/2018	8:43	Placed	10499834	WSE/Temp	30 min
17	MCNA	MCNA1- N channel	6/24/2019	9:51	Removed	10499834	WSE/Temp	30
18	MCNA	MCNA1- N channel	6/24/2019	9:51	Removed	20112565	DO	30
19	MCNA	MCNA1- N channel	6/24/2019	9:55	Placed	20149615	WSE/Temp	30
20	MCNA	MCNA1- N channel	12/13/2018	8:43	Removed	20358333	WSE/Temp	15 min
21	MCNA	MCNA1- N channel	12/13/2018	8:43	Placed	NEED #	DO	30

Figure 11: Example image of a Deployment Log.

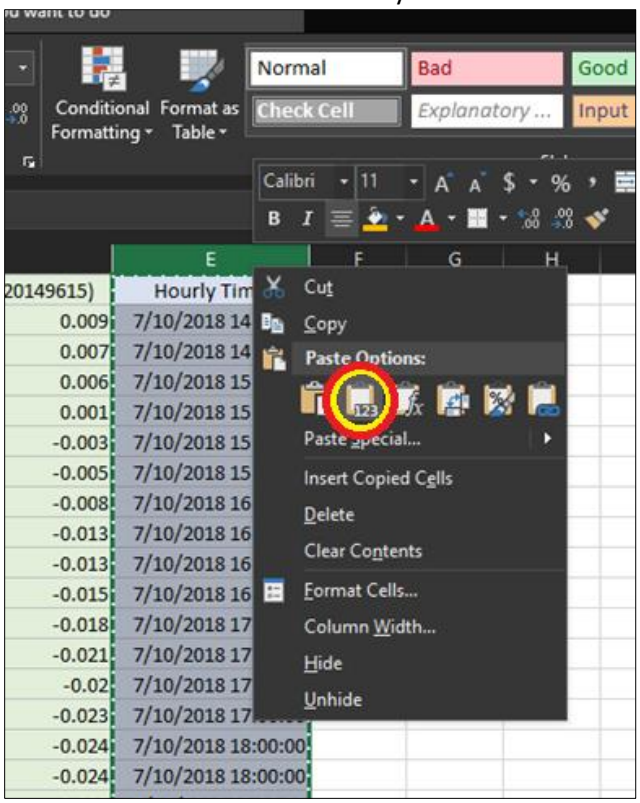
The logger located at MCNA1 – SN 10499834 was placed at 12/13/2018 at 8:43 am and removed on 6/24/2019 at 9:51 am, so any data collected before 9am on 12/13/2018 and any data after 9:30 am 6/24/2019 should be trimmed from the data set. If the data set crosses a time boundary, this needs to be considered as HOBOware does not correct for daylight saving time: make sure the hobofile and the time stamp data is the same (GMT-7) to ensure the correct data is trimmed from the beginning and the end. **BEFORE FURTHER CLEANING DATA, COLLAPSE INTO HOURLY (OR GO TO STEP 11 BELOW TO KEEP ORIGINAL TIME INTERVAL)**

7. **If data is collected at an interval less than 1 hour (such as every 30 mins or 15 mins),** add create a new column for "Hourly Time", then add this formula into this new column:

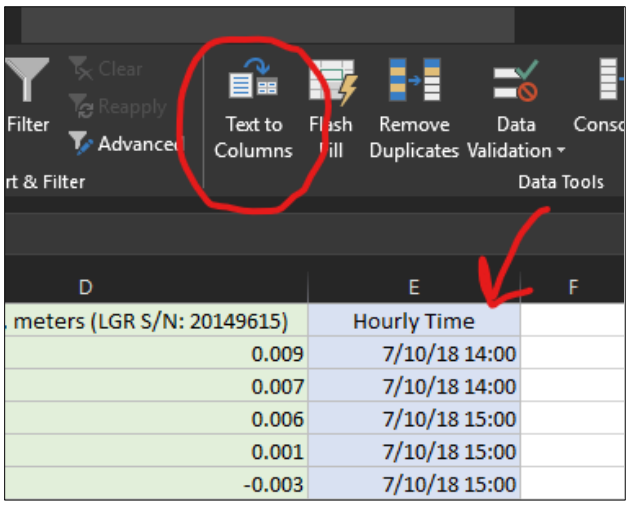
=(MONTH(CELL)&"/"&DAY(CELL)&"/"&YEAR(CELL))&" "&HOUR(CELL)&":00:00"

Replace "CELL" will the first cell of the "Date Time" column (from Figure 10), then autofill the remaining cells, this will create date time stamps that are hourly and make for easy data summarization by the hour.

8. Paste as values to remove Hourly Time formula and make sure these values are set as Dates.

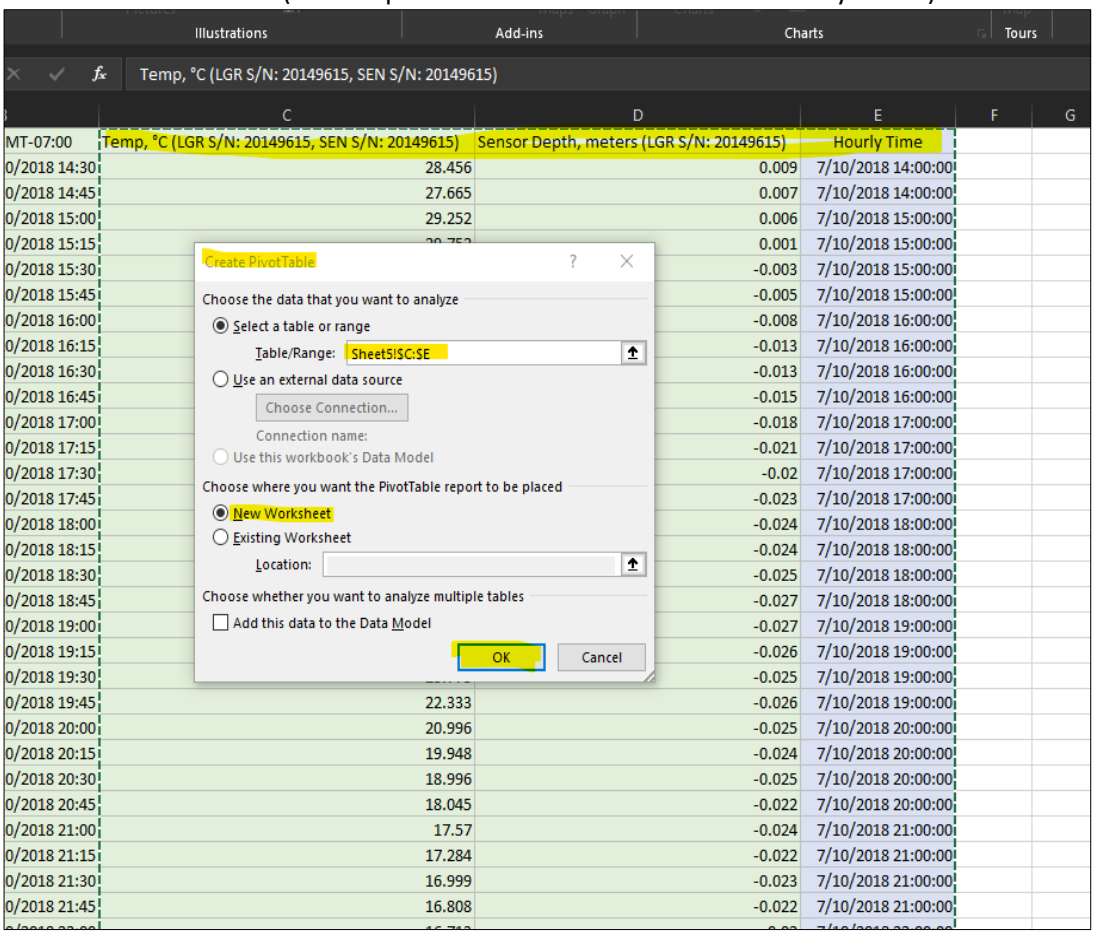


And then use the Text to Columns function under the Data Tab to make sure these time-date data are correctly stored as date data (select column and then click on "Text to Columns" button (click through prompts)).



9. Use this new Hourly Time column to collapse sensor depth data into hourly data using a **pivot table**

- Insert a Pivot Table with Temp, Sensor Depth, and Hourly Time columns selected, add to New Worksheet (in example workbook this is labeled as “Hourly Pivot”):



- Set the Hourly Time as the Row (not grouped) and the Temp and Sensor Depth as average of values:

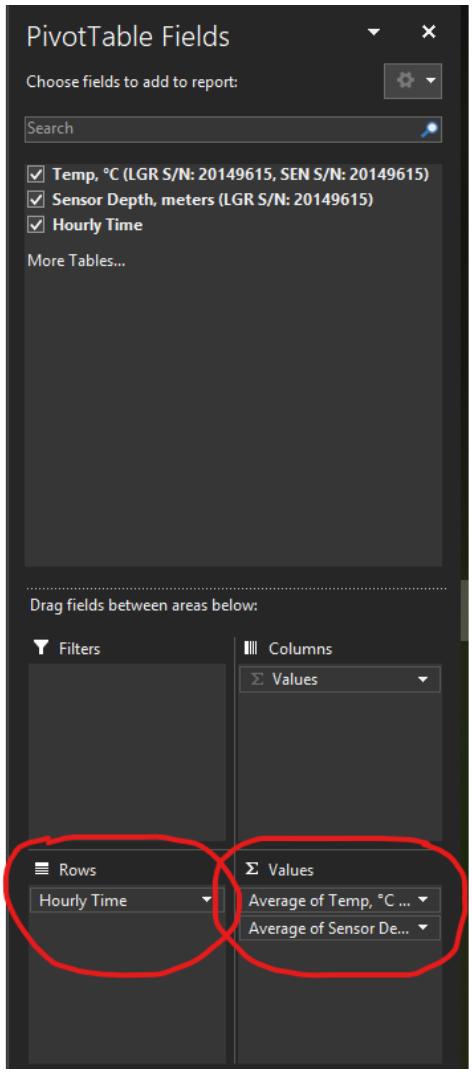


Figure 12: Pivot Table Arrangement Tab

10. Once the pivot table has collapsed the data into hourly, copy and paste (as values) the entire pivot table into a new worksheet for final cleaning, fix number and date types and relabel headers as needed. The pivot table should look like the image below. (This new sheet is labeled "Hourly Editing" in the example workbook)

	A	B	C	D
1				
2	Hourly Time	Average of Temp, °C (LGR S/N: 20149615, SEN S/N: 20149615)	Average of Sensor Depth, meters (LGR S/N: 20149615)	
3	7/10/18 14:00	28.0605	0.008	
4	7/10/18 15:00	29.77825	-0.00025	
5	7/10/18 16:00	31.80575	-0.01225	
6	7/10/18 17:00	27.5225	-0.0205	
7	7/10/18 18:00	25.46475	-0.025	
8	7/10/18 19:00	24.21025	-0.026	
9	7/10/18 20:00	19.49625	-0.024	
10	7/10/18 21:00	17.16525	-0.02275	
11	7/10/18 22:00	16.37975	-0.017	
12	7/10/18 23:00	15.44925	-0.01375	
13	7/11/18 0:00	14.99575	-0.01025	
14	7/11/18 1:00	15.9505	-0.009	
15	7/11/18 2:00	15.9985	-0.00425	
16	7/11/18 3:00	15.54475	-0.00325	
17	7/11/18 4:00	15.09125	-0.005	
18	7/11/18 5:00	14.7565	-0.0055	
19	7/11/18 6:00	14.68475	-0.00475	
20	7/11/18 7:00	16.593	-0.00175	

Figure 13: Resulting Pivot Table with Hourly Temp-Sensor depth data

START HERE IF DATA IS ALREADY IN AN HOURLY INTERVAL (OR SKIP ABOVE STEPS TO KEEP DATA IN SUB-HOURLY RESOLUTION):

11. Insert 3 new columns with headers for **Final Depth, Final Temp, and Final WSE.**

	A	B	C	D	E	F	G
1							
2	Hourly Time	Average of Temp, °C	Average of Sensor Depth	Final Temp	Final Depth	Final WSE	
3	7/10/18 14:00	28.06	0.01				
4	7/10/18 15:00	29.78	0.00				
5	7/10/18 16:00	31.81	-0.01				

12. The **Final Temp** column must only include temperature measurements when the depth was more than 0.15m and when temperature was above zero degrees Celsius. This can be done by using this formula:

    =IFS(CELL "Average of Sensor Depth" <0.15, "Exposed", CELL "Average of TEMP" <0, "NA", TRUE, CELL "Average of TEMP")

    Replace "**CELL "Average of Sensor Depth"**" with the first cell in the sensor depth column and "**CELL "Average of TEMP"**" with the first cell in the sensor temp column, then copy this formula for all cells – This formula replaces temp with "Exposed" when sensor is exposed (<0.15 meters) and NA when Temp is below 0^{o}C.

13. The **Final Depth** column must only include positive values >/= 0m, accompanied by temperatures above zero degrees Celsius. This can be done by using this formula:

    =IFS(CELLTEMP <0, "NA", TRUE, ROUND(IFS(CELLDEPTH <0, "0.0", TRUE, CELLDEPTH),2))

    Replace "CELLDEPTH" with the first cell in the "Average of sensor depth" column and "CELLTEMP" with the first cell in the "Average of temp" column, then copy this formula for all

cells – This formula replaces depth with "NA" when the temperature is below 0°C and then replaces depth with 0 when the sensor depth is negative.

14. Create the **Final WSE** column by adding the sensor depth to the sensor elevation which can be found in the deployment log (be careful with editing multiple deployments with different installed elevations) using this formula:

    =IFS(CELLDEPTH <=0, "Dry", CELLTEMP>=0, (CELLFINALDEPTH +SENSORELEVATION), TRUE, CELLFINALDEPTH)

    Replace "CELLDEPTH" with the first cell in the "Average of sensor depth" column, CELLTEMP with first cell in "Average of temp" column, "CELLFINALDEPTH" with first cell in **Final Depth** column, and "Sensor Elevation" with the sensor elevation reported in the deployment log, then copy this formula for all cells – This formula reports the WSE as "Dry" when the water depth is <=0 and "NA" when temperatures are below 0°C.

15. Copy all 3 new columns and paste as values to remove equations, then use the *Text to Columns* function to correct data formatting issues with each column, then graph these data to look for anomalies and fix any issues. The final product of these steps should result in a table that looks like the one in the image below:

	Hourly from Pivot			Formulas			Final Values		
Date	Hourly DateTime (GMT -7)	Average of Temp, °C	Average of Sensor Depth, meters	Final Temp	Final Depth	Final WSE	Temp	Depth	WSE
7/10/2018	7/10/18 14:00	28.06	0.01	Exposed	0.008	3.078	Exposed	0.01	3.08
7/10/2018	7/10/18 15:00	29.78	0.00	Exposed	0.0	Dry	Exposed	0.00	Dry
7/10/2018	7/10/18 16:00	31.81	-0.01	Exposed	0.0	Dry	Exposed	0.00	Dry
7/10/2018	7/10/18 17:00	27.52	-0.02	Exposed	0.0	Dry	Exposed	0.00	Dry
7/10/2018	7/10/18 18:00	25.46	-0.03	Exposed	0.0	Dry	Exposed	0.00	Dry
7/10/2018	7/10/18 19:00	24.21	-0.03	Exposed	0.0	Dry	Exposed	0.00	Dry
7/10/2018	7/10/18 20:00	19.50	-0.02	Exposed	0.0	Dry	Exposed	0.00	Dry
7/10/2018	7/10/18 21:00	17.17	-0.02	Exposed	0.0	Dry	Exposed	0.00	Dry
7/10/2018	7/10/18 22:00	16.38	-0.02	Exposed	0.0	Dry	Exposed	0.00	Dry
7/10/2018	7/10/18 23:00	15.45	-0.01	Exposed	0.0	Dry	Exposed	0.00	Dry
7/11/2018	7/11/18 0:00	15.00	-0.01	Exposed	0.0	Dry	Exposed	0.00	Dry
7/11/2018	7/11/18 1:00	15.95	-0.01	Exposed	0.0	Dry	Exposed	0.00	Dry
7/11/2018	7/11/18 2:00	16.00	0.00	Exposed	0.0	Dry	Exposed	0.00	Dry
7/11/2018	7/11/18 3:00	15.54	0.00	Exposed	0.0	Dry	Exposed	0.00	Dry
7/11/2018	7/11/18 4:00	15.09	-0.01	Exposed	0.0	Dry	Exposed	0.00	Dry
7/11/2018	7/11/18 5:00	14.76	-0.01	Exposed	0.0	Dry	Exposed	0.00	Dry

Preparing Data for Database Submission

16. Add new sheet in workbook for finalized stacked data label "Final". Copy-paste Hourly DateTime, and the Final values of Temp, Depth, WSE data from previous worksheet (make sure these are no longer formulae).

17. To create a database and to aid in long-term data management, add new sheet in workbook to stack data and label this "Database". Add headers: Site, Type, Date, DateTimeHr, Temp, Sensor Depth and WSE. Copy data from "Final" Sheet into this sheet by stacking the Temp, Depth, WSE data on top of each other (see attached workbook for example). Once the data is stacked it can be checked for errors using a pivot table (labeled Pivot_Database in example workbook). Once finalized these data can then be added to the master database. Save this processing workbook as metadata for others to refer to incase any errors in the data are discovered in the future.

18. Once data is combined and stacked into a master database (excel workbook), insert pivot table for these data and you should be able to graph and summarize these data easily. See example database and pivot table in associated folder.

Data Management and Analysis

To effectively manage hydrology data, establish a unified database format and employ a program like Tableau Prep to consolidate the dataset, as demonstrated in Table 2.

Table 2: Hydrology database format, add more attributes as needed.

Site	Logger Name	DateTime	WSE	Temp	Depth

Handling vast datasets, particularly from continuous water quality monitoring, can be cumbersome using traditional spreadsheet tools. Notably, Excel's capacity is tested when dealing with sizable datasets, such as those generated from hourly water quality readings over prolonged periods. In these scenarios, tools like Tableau Prep become invaluable. These platforms not only manage extensive datasets with relative ease but also provide versatility in integrating data across varied formats, from Access databases to individual text files. By leveraging such tools, analysts can seamlessly transition between sites for comparative assessments and incorporate new monitoring locations using a consistent data structure. For a compelling visualization of the analytical outcomes, consider deploying an online dashboard. An example can be found in the LCEP 2023 report by Kidd et al. 2023.

Time Series Analysis

Engage in time series analyses to compare trends within data. This approach provides juxtapositions across various factors: sites, years, months, reaches, or any other subdivisions the data resolution permits.

Import hydrology data into Tableau to craft both continuous hydrographs and annual visuals. Use annual graphs to draw comparisons between dry and wet years, while continuous plots help in identifying broader hydrograph trends.

For temperature data, compute the 7-day moving temperature maximum, targeting days where temperatures exceed 25°C — a notable threshold for salmonids in specific Columbia County watersheds (Figure 14).

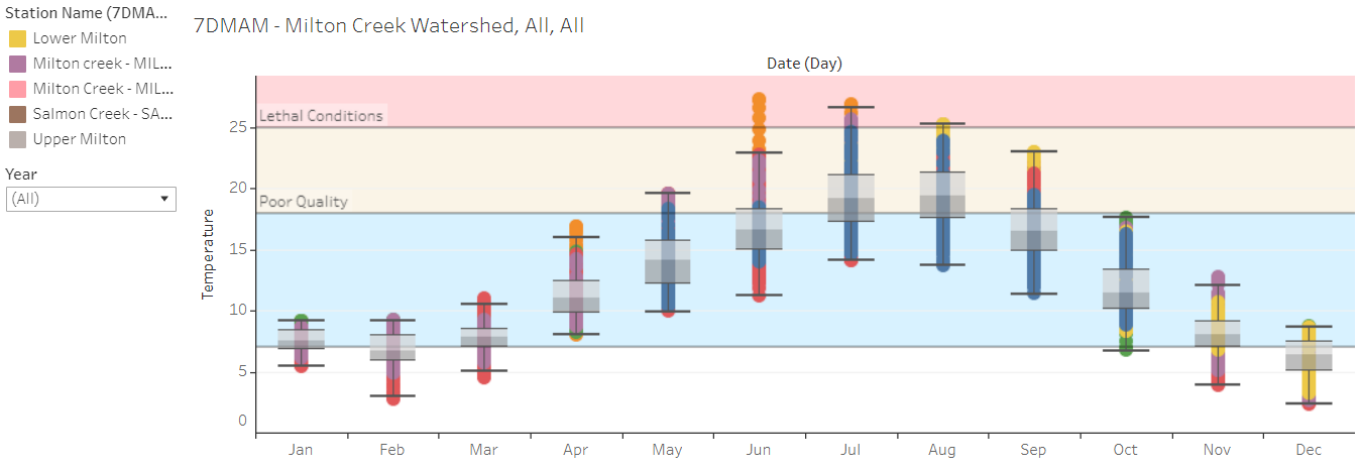


Figure 14: Milton Creek Watershed 7DMAM of temperature. 2017-2021 (LCEP 2023).

Temperature, Depth, and Dissolved Oxygen - Known Thresholds

Different environmental metrics offer valuable insights into the habitat requirements of aquatic organisms. For instance, certain temperature conditions are crucial for salmon survival, amongst other species. If a water body consistently records temperatures above 30°C during summer, it's likely not a suitable habitat for salmon during those months.

Various fish species have specific threshold and lethal values related to environmental metrics such as temperature, depth, and dissolved oxygen (Table 3). These values, derived from scientific studies, provide vital clues about the viability of habitats for different species. However, it's important to note that some of these values are primarily obtained under controlled laboratory conditions. Consequently, there can sometimes be debates within the scientific community regarding the precise values and their real-world applicability. For a deeper understanding and for specific thresholds, one should consult the comprehensive literature and databases on the subject.

Table 3: Fish threshold and lethal metrics (taken from Holmen et al. 2011).

Parameters	Need	Acceptable Range	Source
***E. coli* Bacteria**	**General**	<406 MPN/100ml (DEQ) or <235 MPN/100ml (EPA)	DEQ regulatory standards (OAR 340-041), EPA recommended Criteria
Turbidity	**Salmon Habitat**	<10 NTU	University of Wisconsin Extension 2006
Temperature	**Salmon Habitat: Year-round**	18°C 7-day moving average maximum (7dMAM)	DEQ regulatory standards for salmonid rearing habitat
Temperature	**Salmon Habitat: Healthy Adult**	7.2-15.6°C (>25 °C Lethal)	OWEB Water Quality Technical Manual
Temperature	**Salmon Habitat: Healthy Juvenile**	12.2-13.9°C (>25 °C Lethal)	OWEB Water Quality Technical Manual

pH	**General**	6.5-8.5 SU	DEQ regulatory standards for Willamette Basin
Dissolved Oxygen (DO)	**Salmon Habitat**	≥11mg/L (<6mg/L Lethal)	DEQ regulatory standards

Habitat Opportunity Analysis:

The core essence of the "habitat opportunity" analysis is to quantify the temporal suitability of sites for aquatic species, with salmon being a prime focus (Figure 15). This involves the careful evaluation of depth, temperature, and the duration of inundation to ascertain habitat viability (Schwartz and Kidd et al. 2018).

Duration and Depth Analysis:

A pivotal component of this holistic habitat evaluation is understanding the interplay between water depth and its duration across varying wetland elevations. By analyzing how long specific areas remain submerged (or remain dry), we glean insights into the potential habitat suitability for a plethora of species. For instance:

Fish: Areas that remain submerged for prolonged periods, but not too deep, could provide safe havens for fish during their crucial developmental stages.

Amphibians: Frogs and other amphibians require specific depths for breeding and foraging. Understanding depth durations can signal whether a habitat is conducive for successful amphibian life cycles.

Wetland Plants: Depth and its persistence can be critical for certain wetland plants. Some plants thrive in transiently inundated areas, while others might require longer submerged periods during the growing season.

By weaving these depth-duration parameters with seasonality, and temperature data, we get a comprehensive picture of the habitat's capacity to sustain diverse marine and wetland life. For juvenile salmonids, an optimal habitat mandates a water depth of ≥0.5 m for accessibility. Depths below this benchmark can be restrictive. Temperature, too, is a key factor. Waters cooler than 17.5°C are deemed optimal, those between 17.5°C and 22°C are marginal, and anything exceeding 22°C can be inhospitable for salmonids.

Such multifaceted analyses not only enrich our understanding of habitats but also guide conservation and restoration strategies, ensuring that interventions are tailored to the unique needs of the species they aim to support.

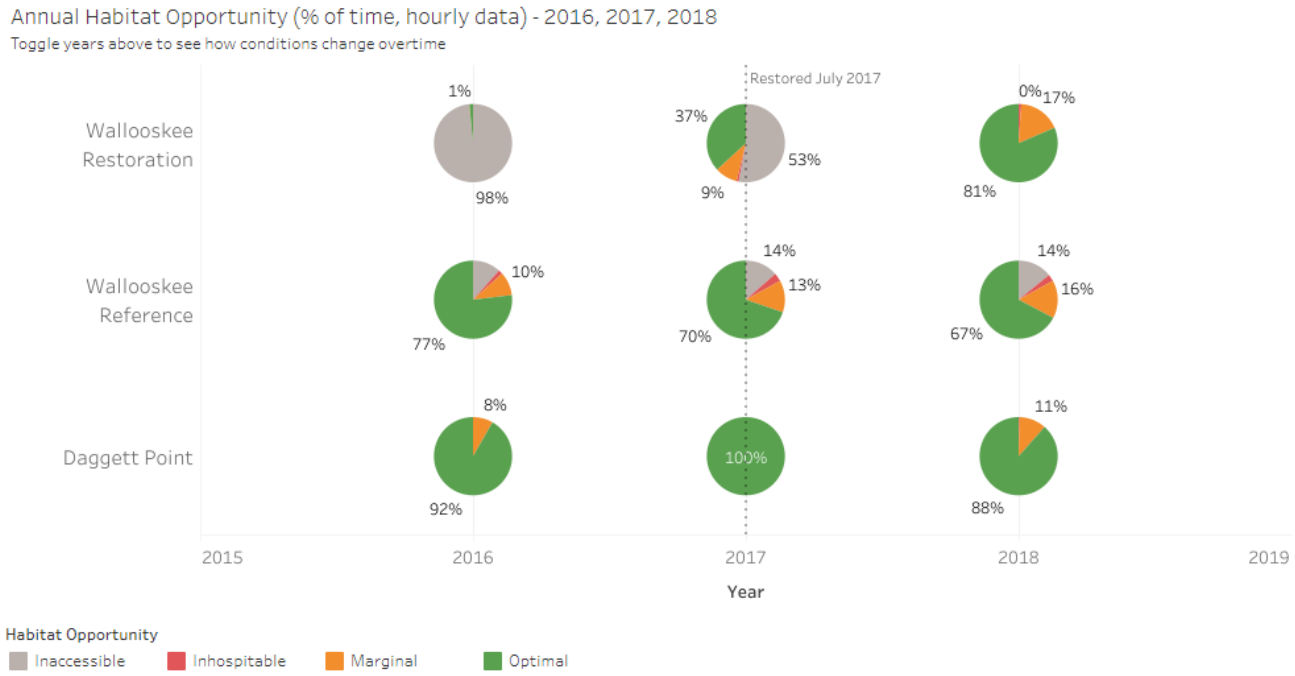


Figure 15: Habitat Opportunity analysis at Wallooskee Youngs Restoration Site, Kidd et al. 2023.

References and Resources

The monitoring protocol can be found on monitoringmethods.org (Method ID815)

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3.2 Tributary Water Surface Elevation, Temperature, Salinity, and Dissolved Oxygen Monitoring

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Background

Tributaries form a crucial component of the riverine network, acting as conduits that transport nutrients, sediment, and freshwater into main water bodies. They also provide critical habitats for various aquatic species. The Lower Columbia tributaries, in particular, harbor habitats essential for several Endangered Species Act (ESA)-listed species, including fall Chinook, coho, chum salmon, winter steelhead, cutthroat trout, and Pacific lamprey. These waterways offer invaluable off-channel habitats and serve as cold water refugia, areas where species can find respite from unsuitably warm water temperatures.

However, over time, human activities such as stream channel modifications, commercial timber production, agriculture, and rapid residential and commercial development have posed significant threats to these habitats. The resultant habitat degradation emphasizes the importance of closely monitoring key water quality parameters like temperature, salinity, and dissolved oxygen, as these are direct indicators of stream health and the overall vitality of the ecosystem.

Objective

Understanding the health and status of our tributaries is imperative for effective conservation strategies. As such, monitoring efforts are designed to paint a comprehensive picture of tributary conditions. This can be achieved by pairing tributary monitoring with grab samples or simplified water surface elevation (WSE) and temperature monitoring. However, monitoring tributaries comes with its own set of challenges. For instance, many of these water bodies become too shallow during the summer months, making the installation of standard logger housing difficult. Additionally, accessing many tributaries can be problematic, especially during peak flow conditions due to their turbulent nature or location.

Given these complexities, this protocol aims to offer clear and practical guidance on effectively monitoring tributaries, ensuring that data collection is both consistent and robust, enabling informed decisions for habitat restoration and conservation.

State Guidelines Adherence

While our protocols are primarily designed around the recommendations and requirements of the State of Oregon, they also align with general water quality requirements mandated by the State of Washington. Researchers intending to fulfill specific state requirements should consult the respective state authorities to ensure their research plan meets the necessary criteria. This is particularly crucial for those projects that might be aiming to adhere strictly to Washington's mandates, as our protocol uses Oregon's standards as a reference for best practices.

Materials

- Hydrology Logger (temperature, WSE, DO)
- Rebar, fence post, and/or metal cabling
- Mallet or post pounder (if using rebar or a fence post)
- Zip ties
- Weights (e.g., fishing weights; depending on logger placement)
- YSI or NIST

Methods

Monitoring Locations

To ensure comprehensive monitoring, a minimum of two locations per tributary should be selected: one upriver and another near the tributary's mouth. For expansive watersheds, more monitoring spots may be needed, reflecting diverse land-use practices. Monitoring should also encompass junction points of contributing tributaries. However, the number of locations hinges on available funding and the specific research questions posed.

Choosing accessible sites is vital. Ensure public access, and when monitoring private lands, always seek the landowner's permission. Once a monitoring spot is selected, document its latitude and longitude (preferably in WGS 84 or NAD83 formats). This geographical data, along with other pertinent environmental information, should be shared with ODEQ in the Sample and Analysis Plan (ODEQ 2020) to address the specific monitoring objectives.

Deploying Equipment

Adhere to the guidelines detailed in the continuous water monitoring procedures SOP (DEQ20-LAB-0021-SOP), which aligns with the State of Oregon's Department of Environmental Quality data collection standards. Loggers should be positioned deep enough within the tributary to gather data from well-mixed sections.

Choose a location close to the stream's edge on the cutbank, where the water is deepest. Ideally, this would be near a tree root ball that's firmly anchored and poses no risk of getting uprooted. If such sites are scarce, consider embedding a fence post or rebar into the ground as an anchor. Secure the logger using metal cabling, attached either to the root ball, rebar, or fence post. For added security, create a secondary loop at the cable's end and use a zip tie to fasten the logger. If you're deploying a temperature-only logger, add weights to ensure it remains submerged. For DO and WSE loggers, house them in perforated PVC pipes to shield them during high water flow events.

While deploying equipment, it's essential to document environmental data that relates to your monitoring objectives. Capture metrics like temperature, water depth, and the distance from the water surface to the sensor. If deploying DO or Conductivity loggers, record additional readings such as conductivity and dissolved oxygen during each servicing. Taking extra measurements using tools like the YSI and collecting a grab sample could offer added insights.

Regularly maintain your equipment. Aim to service and retrieve data from the logger monthly, and use tools like the NIST or YSI to collect supplementary on-site readings during these visits. Replace the logger quarterly and before any anticipated storm events.

Data Management

Storage and Organization:

Timely and detailed data management is critical for preserving the accuracy and accessibility of collected information. All raw data, documented in datasheets, must be systematically organized, categorized, and securely stored. After every field day, it's prudent to create digital copies by scanning these datasheets.

Digital Conversion and Database Creation:

For effective analysis and sustained storage, transcribing this data into organized Excel spreadsheets is advisable. Employing platforms like Tableau for data visualization and integration aids in developing a comprehensive, long-term database that's both accessible and suited for analysis.

Datalogger Data:

Field-acquired datalogger data needs to be diligently converted into a digital format. This digitally structured dataset is pivotal for forming time series analyses, in line with the strategies detailed in section 3.1.2.

Submission, Sharing, and Updates:

While specific guidelines, like those from the Oregon DEQ, stress the importance of promptly sharing continuous data and related environmental metrics, it's beneficial to adopt a wider view on data sharing. This can aid collaborative endeavors and broad-scale studies. Implementing a standardized method for data collection and sharing ensures uniformity and comparability across different studies. By adhering to such standards, the quality of meta-studies and multi-source analyses can be enhanced. Even if researchers are operating outside Oregon or in a different state, it's essential to be aware of and adhere to local or state-specific guidelines. It's always advisable to liaise with local environmental agencies or governing bodies to ensure compliance. Regularly revisiting and updating the SAP (Sample and Analysis Plan) ensures that it accurately reflects the ongoing study parameters and goals.

Analysis

Tailored Data Analysis:

The approach to data analysis is inherently tied to the unique monitoring objectives and inquiries set at the beginning of a project.

Temperature Metrics:

For temperature data, a frequent analytical method involves determining the 7-day moving average maximum (7DADM). This provides insights into temporal temperature variations and outliers. Additionally, it's insightful to ascertain the days when temperatures surpass the recommended thresholds for specific habitats, such as salmon rearing areas.

Dissolved Oxygen Metrics:

Dissolved Oxygen (DO) remains a pivotal metric for gauging aquatic health. In analyzing this data, establishing both the minimum and maximum DO levels over the monitoring timeframe is crucial. These metrics provide a snapshot of the water's ability to sustain diverse marine life forms.

References and Resources

The monitoring protocol can be found on monitoringmethods.org (Method ID: 3982).

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3.3 Water Quality Grab Sampling – for QA/QC or Ongoing Data Collection

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Background

Grab sampling plays an essential role in our Columbia County Water Quality Monitoring Program. We collect water samples for *E.coli* analysis and for turbidity. As per ODEQ QAPP 2021, in-situ, instantaneous measurements also qualify as grab samples. In context of our water quality monitoring program, we have collected temperature, pH, dissolved oxygen (DO) and conductivity as in-situ measurements. While grab samples provide an inexpensive snapshot of water quality at a specific point in time, long-term data collection over a specific time interval provides a large dataset of water quality parameters that provide an insight into water quality in tributaries and watersheds.

We have also worked with the Oregon DEQ to develop and implement a Sample and Analysis plan (DEQ20-VOL-0034-SAP), which outlines the project tasks as well as our sampling procedures for Program parameters.

Objective

Grab samples are an inexpensive method to monitor specific trends in streams and other bodies of water. This protocol should be used in combination with ODEQ QAPP and MOMS to collect grab samples and in-situ instantaneous measurements.

Materials

- Sample bottles
- Ice packs
- Coolers
- YSI or NIST
- Datasheet

Methods

Source materials from Oregon DEQ Quality Assurance (QAPP) and DEQ Mode of Operations Manuals (MOMS).

It is beneficial to conduct grab sampling in areas close to where continuous dataloggers are deployed. However, collecting grab samples over regular intervals also provides sufficient information. For more information, please refer to ODEQ QAPP for sampling methodology of specific parameters. Below are some methods used by LCEP for the water quality monitoring program. For more information, please refer to our Sample and Analysis plan (DEQ20-VOL-0034)

Temperature, Conductivity, pH and DO are measured at the same locations where temperature loggers are deployed and turbidity, *E. coli* samples are collected. These measurements are made in-situ using a Yellow Spring Instruments (YSI) Handheld Sonde. These measurements are recorded in a data sheet

along with the name of site, date and time of measurement along with water depth at the sampling location.

Turbidity and *E.coli* sampling are at the same locations where temperature loggers are deployed. The sampling occurs monthly throughout the year. Sampling sites for turbidity are based on major land use changes from forested to developed. Using major land use changes helps define potential inputs and land use practices contributing to increased turbidity in water bodies. Samples will be collected concurrently with temperature checks. One duplicate sample should be collected per sampling event. *E.coli* samples are collected in bottles with a preservative and placed on ice until hand-off to the analysis lab. The analysis lab provides Chain-of-Custody (COC) sheets which is used for sample record keeping.

Hand grab samples and YSI should be collected by wading into the water, walking upstream, looking for areas that are well mixed, and collecting the sample facing upstream. A sampling pole will be used if high water prevents access to a representative proportion of the stream. Collected samples will be sealed and logged for date, time, and site.

It should be noted that modification of any parameter or sampling design must be updated in the SAP and approved by ODEQ.

Data Management and Analysis

Data Management for grab samples is similar to procedures described in sections 3.1 and 3.2.
Grab sample water quality data are summarized and compared to standard parameter ranges for ideal salmonid habitat as defined by the ODEQ, OWEB, and Environmental Protection Agency (EPA) (EPA 2001, OWEB 2001, ODEQ 2003).

Parameters	Need	Acceptable Range	Source
***E. coli* Bacteria**	**General**	<406 MPN/100ml (DEQ) or <235 MPN/100ml (EPA)	DEQ regulatory standards (OAR 340-041), EPA recommended Criteria
Turbidity	**Salmon Habitat**	<10 NTU	University of Wisconsin Extension 2006
Temperature	**Salmon Habitat: Year-round**	18°C 7-day moving average maximum (7dMAM)	DEQ regulatory standards for salmonid rearing habitat
Temperature	**Salmon Habitat: Healthy Adult**	7.2-15.6°C (>25 °C Lethal)	OWEB Water Quality Technical Manual
Temperature	**Salmon Habitat: Healthy Juvenile**	12.2-13.9°C (>25 °C Lethal)	OWEB Water Quality Technical Manual
pH	**General**	6.5-8.5 SU	DEQ regulatory standards for Willamette Basin
Dissolved Oxygen (DO)	**Salmon Habitat**	≥11mg/L (<6mg/L Lethal)	DEQ regulatory standards

Time series trends for parameters and monthly variations allow us to compare trends across years and sites, which is a powerful tool to understand the evolution of a particular parameter in question. We use

Tableau to create these box and whisker plots, overlaid on ODEQ and EPA thresholds, which informs us on the time-periods of concern.

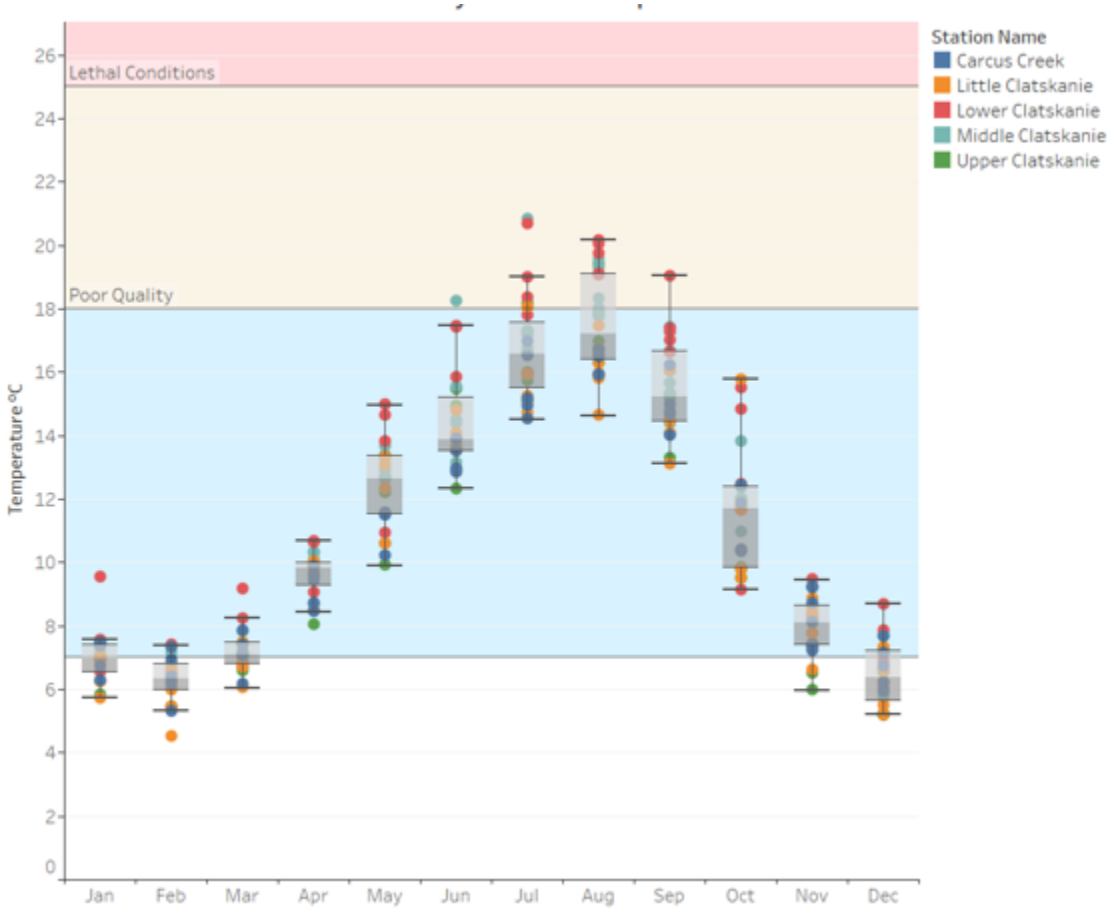

Figure 16: Monthly variation in temperature overlaid on ODEQ thresholds for Salmon rearing habitat (LCEP 2023)

While it is important to study time series trends through grab data, it is important to tie these trends back to land-use practices in the tributaries and watersheds, to fully understand the evolution of study parameters.

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The monitoring protocol can be found on monitoringmethods.org (Method ID 816).

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3.4 Water Quality Monitoring for Abiotic Conditions

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Background

There are two in-situ water quality monitoring platforms in the mainstem Columbia River that provide baseline water quality measurements in support of the Ecosystem Monitoring Program. The first platform, purchased through funding from the National Science Foundation, was installed in July 2009 at River Mile 53 (in Reach C) and is physically located on a USGS Dolphin piling (46 11.070 N, 123 11.246 W; Figure 5). A second platform, funded by the Ecosystem Monitoring Program, was installed in August 2012 at River Mile 122 (in Reach G) and is physically located on the outer-most floating dock at the Port of Camas-Washougal (45 34.618 N, 122 22.783 W; Figure 5).

In addition to the sensors deployed on the mainstem, continuous abiotic conditions are also measured by Yellow Springs Instruments (YSI) models 6600EDS and 6920V2, equipped with water temperature, specific conductance, pH, and dissolved oxygen probes. YSI EXO2 units are also equipped with fluorometers. Addition of a fluorometer provides a capability to detect and monitor chlorophyll a and phycocyanin, pigments that approximate the biomass of total phytoplankton and cyanobacteria, respectively.

Objective

In addition to capturing spatial and temporal resolution of basic water quality and biogeochemical observations for the mainstem Columbia River, an outcome of this effort is to provide daily estimates of parameters necessary for the assessment of ecosystem conditions at sites upstream and downstream of the Willamette-Columbia confluence. Knowledge of daily conditions at these sites allows the identification of contributions from tributaries in the lower Columbia River. Availability of these data enables the calculation of fluxes of various inorganic and organic components, such as nitrate concentration or chlorophyll, an estimate of phytoplankton biomass. Knowledge of nutrients and organic matter flux for a large river is important for a variety of applications, including assessment of pollution, an indication of eutrophication, and quantification of material loading to the coastal zone, where many important ecological processes may be affected. Another product is the assessment of Net Ecosystem Metabolism (NEM), which provides a daily measure of the gross primary production and aerobic respiration occurring in the river as measured by hourly changes in dissolved oxygen. NEM is often used by managers to identify changes or impairments to water quality (Caffrey 2004).

Materials and Methods

Each instrument platform consists of a physical structure, sensors, sensor control, power supply and distribution, and wireless communication, in the case of LOBO sensor platforms in the mainstem river. Data transmitted from the sensors is available within 1–2 hours of collection. Raw data can be downloaded in near-real time from a dedicated webpage (http://columbia.loboviz.com/). For the EXO sondes, data are downloaded directly from the instruments in the field or back in the laboratory.

Table 4. Description of the components on the LOBO sensor platforms located at RM-53 and RM-122. Note that the LOBO system was deployed from January through June; after this, the system consisted of a YSI sonde equipped with temperature, conductivity, and dissolved oxygen.

Company	Sensor	Parameters
SeaBird (formerly Satlantic)	LOBO	Power distribution Sensor control Wireless communication Data management
SeaBird (formerly WET Labs)	WQM Water Quality Monitor	Conductivity, Temperature, Dissolved Oxygen, Turbidity, Chlorophyll *a* Concentration

Table 5. Range, resolution, and accuracy of Yellow Springs Instruments (YSI) models 6600EDS and 6920V2 water quality monitors. M, meters; °C, degrees Celsius; µS/cm, microsiemens per centimeter; mg/L, milligrams per liter.

Monitoring Metric	Range	Resolution	Accuracy
Temperature	-5–70°C	0.01°C	±0.15°C
Specific conductance	0–100,000 µS/cm	1 µS/cm	±1 µS/cm
ROX optical dissolved oxygen	0–50 mg/L	0.01 mg/L	±0–20 mg/L
pH	0–14 units	0.01 units	±0.2 units

Sensor Maintenance

The sensors are designed to operate autonomously, at high temporal resolution (hourly), and over long periods between maintenance (estimated at three months, although sensors are typically maintained at shorter intervals). This is achieved through a design that maximizes power usage and minimizes biofouling. Antifouling is achieved through the use of sunlight shielding (to prevent algae growth), window wipers, copper instrument surfaces, and bleach injection of the internal pumping chamber. Maintenance trips include cleaning of all sensors and surfaces and performing any other needed maintenance. Additionally, water samples are collected for laboratory analysis of nutrients and chlorophyll a. Maintenance activities took place approximately every three weeks in order to change the batteries, clean and calibrate the instruments, download data, and make any necessary adjustments.

Sensor Calibration

Initial sensor calibration was performed by the manufacturer. Each instrument is supplied with a certificate of calibration, and where appropriate, instructions for recalibration. For example, the Seabird SUNA for nitrate measurements operates with a calibration file determined at the factory under strictly controlled environmental conditions but which can be periodically checked and modified for sensor drift by performing a "blank" measurement at our OHSU laboratory using deionized water. At longer intervals (every 1–2 years) the sensors are returned to the factory for maintenance and recalibration.

During periodic sensor maintenance, water samples are collected for additional quality control criteria. At RM-53, samples are collected for nutrients and chlorophyll *a* samples and returned to the laboratory at OHSU for processing and analysis using established laboratory techniques (EPA, 1983; APHA, 1998; Welschmeyer, 1990). Laboratory-based discrete measurements of chlorophyll *a* are used to correct the

in situ fluorometer measurements. The discrete samples and the corresponding sensor data for nitrate and chlorophyll *a* are shown in Table 6.

Table 6. Comparison of in situ sensor data with laboratory measurements of nitrate and chlorophyll a in water samples.

Location/Parameter/# measurements	Regression equation
RM-122/Nitrate/46	$Y = 0.95x + 1$ $r^2 = 0.99$
RM-122/Chl/13	$Y = 0.8x + 1$ $r^2 = 0.93$

Nutrients

Nitrogen and phosphorus are dissolved nutrients that are often present at low enough concentrations to limit plant and phytoplankton growth in aquatic environments relative to other growth requirements. Conversely, in many water bodies, high levels of these nutrients arise from fertilizer and other inputs, which leads to the impairment of water quality following the stimulation of algal and bacterial growth. To analyze water column nutrient concentrations, two 1 L water grab samples were collected from representative open water areas within the sites and subsampled before processing. Three fractions were determined from the subsamples: (1) dissolved inorganic species of nitrogen and phosphorus (nitrate, nitrite, ortho-phosphate, ammonium), (2) total dissolved nitrogen and phosphorus (TDN, TDP), and (3) total nitrogen and phosphorus (TN, TP). Nitrate+nitrite and orthophosphate were determined according to EPA standard methods (EPA 1983), ammonium was determined colorimetrically (APHA 1998), and total phosphorus was determined according to USGS (1989). Detection limits for each ion or species are given in Table 7.

Table 7. Detection limits for colorimetric analysis of nitrogen and phosphorus species. TDN = total dissolved nitrogen, TN = total nitrogen, TDP = total dissolved phosphorus, TP = total phosphorus.

Ion or element	Detection limit (mg/L)
Ammonium	0.00280134
Nitrate + Nitrite	0.00700335
Nitrite	0.00140067
TDN	0.01540737
TN	0.1960938
Phosphate	0.00619476
TDP	0.00619476
TP	0.9601878
Silicic acid	0.0280855

Data Management and Analysis

Data management consists of quality control steps to remove outliers before computing daily averages from hourly measurements. The daily data are used for plotting and analysis.

Raw data are stored as text files and csv files in a secure, password-protected cloud platform for access by project personnel. Derived data are stored in separate Excel files. The derived data consist of calculations of daily averages, day-equivalents (i.e. number of hours corresponding to the quantity of interest expressed in days), as well as maximum, minimum, and long-term average values.

Nutrient concentrations are computed by comparing peak values produced in the Astoria Analyzer software to peaks produced in >5-point standard curves for nitrate, nitrite, ammonium, ortho-phosphate, and silicic acid.

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4. Marsh Surface Elevation Monitoring

4.1 Tracking Changes in Tidal Wetland Elevations

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Background

In the dynamic and intricate habitats of the Lower Columbia River Estuary, the elevation of wetlands, floodplains, and riparian forests plays a pivotal role in determining the ecological vitality and suitability of these landscapes for key species, most notably the salmonids. To comprehend the status, trends, and impacts of various environmental or anthropogenic actions on these habitats, it is essential to precisely track the subtle shifts in these elevations over time.

RTK (Real-Time Kinematic) GPS: In the realm of professional elevation monitoring, high-precision surveying tools like the RTK GPS have become indispensable. While both RTK GPS and traditional instruments like auto levels are geared towards obtaining accurate measurements, their mechanisms are distinct. An auto level is an optical device tailored for discerning relative height differences across terrains. On the other hand, RTK GPS harnesses the power of satellite navigation and is amplified by a network of fixed, ground-based reference stations. This synergy allows RTK GPS to achieve real-time positional data with centimeter-level precision. The ability of RTK GPS to consistently adjust to the dynamic satellite signals makes it notably superior in terms of accuracy, adaptability, and immediate feedback, distinguishing it from conventional surveying methodologies.

Utilizing high-precision RTK GPS equipment becomes indispensable in this context for several reasons:

- **Micro-Elevational Changes Matter:** Even slight alterations in elevation can drastically affect water retention, drainage, and the periodicity of tidal inundations. These factors directly impact the health and distribution of plant communities, the aquatic habitat quality, and the behaviors and survival of salmonids.
- **Coordinated Monitoring Efforts:** By co-locating elevation monitoring with the installation of water depth and temperature loggers, a more comprehensive understanding of habitat conditions emerges. The interplay between water levels, temperature gradients, and physical elevation drives the formation and sustenance of essential salmonid habitats.
- **Contextualizing Plant Communities:** Tracking the elevation of plant community monitoring locations offers insights into how varying elevational zones foster different vegetation types. The altitude can dictate the salinity levels, moisture content, and sunlight exposure, all of which shape the vegetation profile.
- **Soil Sampling Relevance:** Soil characteristics, such as salinity, moisture, and nutrient content, are directly influenced by elevation. By monitoring the elevations of soil sample locations, one can contextualize the findings of soil analyses and link them to the physical topography of the site.
- **Channel Dynamics:** Elevation tracking extends its importance to monitoring channel cross-sections. The depth, width, and slope of channels govern water flow velocity, sediment transportation, and erosion patterns, all of which have implications for salmonid habitats.

- **Sediment Erosion and Accretion:** Monitoring sediment benches for erosion and accretion can offer insights into how sediment dynamics are evolving. Precision in elevation tracking can detect even minimal sediment shifts, predicting potential habitat alterations.
- **Restoration Assessment:** Restoration efforts aim to rejuvenate habitats to their optimal conditions for native species. Tracking elevations using RTK GPS before and after restoration interventions provides quantifiable metrics on the effectiveness of these efforts. A comprehensive, precision-based elevation profile establishes a foundation upon which the success or areas of improvement for restoration projects can be evaluated.

In essence, the Lower Columbia River Estuary thrives on its elevational dynamics. Thus, tools like the RTK GPS that offer precision are invaluable in driving informed habitat conservation and restoration decisions.

Objective

Amid the numerous dynamics at play in tidal wetland restoration, hydrologic processes, especially sediment transport, stand out. Wetlands, depending on their past interventions, can either be too sunken leading to unvegetated mudflats post-restoration or too elevated, favoring invasive species like *Phalaris arundinacea*. By monitoring the nuances of sediment erosion, accretion, and the broader elevational shifts, one can glean insights into the wetland's natural succession. This data becomes instrumental in assessing whether the wetland habitats are achieving, or are set on the course to achieve, the desired marsh elevations.

Methods Overview

The core of this section revolves around synchronizing elevation monitoring with other data sets:

- Refer to section **2.2 UAV Photography** for digital elevation model (DEM) generation. Note that while UAVs capture large-scale changes proficiently, their resolution might not extend to minute details. LCEP's latest foray into LiDAR-enabled drones promises unparalleled elevation tracking accuracy. As we familiarize ourselves with this cutting-edge tech, expect detailed integrations in upcoming protocol documents.
- Section **5.1 Plant Community Tracking** dives deep into elevation gradient analysis across sites. An RTK ensures meticulous elevation captures for each vegetation plot. For a temporal evolution, ensure annual repetition of these methodologies.

Best Practices for Collecting and Sharing RTK GPS Elevation Data

Given the exact protocols for collecting accurate RTK GPS can vary depending not only on the make or model of equipment being used but also on the proprietary software employed, we have made this protocol more of an overview of best practices, assuming that the survey team will be knowledgeable in how their own equipment and software are used to collect accurate data.

1. **Unified Datum, Units, and Regional Considerations:** Elevation data should always be referenced to a consistent datum, such as the North American Vertical Datum (NAVD88) or Mean Sea Level (MSL). Additionally, always ensure that the same units (e.g., meters, feet) are used across datasets. Given the Pacific Northwest's unique geological characteristics, those working in the region should be keenly aware of regional vertical datums that might be more appropriate for specific projects within the Estuary. Factors such as post-glacial rebound and ongoing tectonic

activity can influence elevational readings over time, necessitating a keen awareness of these dynamics when tracking changes, given these conditions vary from place to place within the Estuary. For projects spanning the Oregon-Washington border, ensuring state-specific compliance is also essential. In sum, using different datums, units, or not accounting for regional geological dynamics can lead to inconsistencies and incorrect interpretations. It's crucial to always check, note, and if necessary, convert both the datum and the units before analysis to ensure accuracy, comparability, and coherence.

2. **Calibration and Verification:** Regular calibration of RTK GPS units is vital to ensure the accuracy of the data collected. Follow the manufacturer's guidelines closely. After calibration, verify the unit's accuracy by taking measurements at recognized benchmarks or control points. This practice will help identify any discrepancies and correct them before collecting crucial data.
3. **Consistency in Collection:** When conducting surveys, especially in tidal zones, it's essential to standardize conditions. Tidal wetlands, for instance, experience diurnal and seasonal variations. By conducting surveys at consistent tidal stages, like at low tide or mean tide, one can reduce variability in the data, making it more reliable for temporal comparisons.
4. **Satellite Weather and Mission Planning:** Before embarking on a surveying mission, check the predicted satellite conditions. Factors like solar flares, satellite maintenance, or irregularities can influence satellite performance and data accuracy. Using specialized tools or software that predict satellite "weather" can help in planning your survey timings to align with optimal satellite conditions.
5. **Mitigating Poor Satellite Coverage:** In areas with limited satellite visibility (due to natural or built structures) or less-than-ideal satellite constellations, extra precautions are necessary. Consider:
    a. **Antenna Placement:** Ensure the GPS antenna has a clear view of the sky, minimizing obstructions.
    b. External Reference Stations: In areas with limited satellite visibility due to obstructions such as canyons, consider using additional ground-based reference stations for enhanced RTK correction. Alternatively, employ survey tools like auto levels or total stations that don't rely on direct satellite signals.
    c. **Delayed Surveys:** If satellite conditions are transiently poor, consider delaying the survey until conditions improve.
    d. **Multipath Avoidance:** Multipath errors occur when satellite signals reflect off surfaces before reaching the GPS receiver. Select open areas away from reflective surfaces such as tall buildings or water bodies.
6. **Consistent Survey Protocols:** For regions known for fluctuating satellite conditions, maintain a consistent survey protocol. This includes using consistent equipment configurations, following similar surveying paths, and even surveying at consistent times if certain hours provide better satellite conditions.
7. **Optimal Data Resolution:** Based on the scale and objectives of your study, determine the appropriate data resolution. For instance, if you're keen on capturing minute elevational changes, a finer resolution might be preferable. However, for broad landscape analyses, coarser resolution might suffice. Ensure that the chosen resolution captures the necessary details without generating overwhelmingly large datasets.
8. **Detailed Documentation:** Every data point collected should be accompanied by detailed metadata. This should encompass the date and time of collection, equipment model, software version, operator details, environmental conditions, and any other observations that might

influence the reading. Metadata provides valuable context for future analyses and helps interpret anomalies or outliers.

9. **Data Safety and Storage:** Store the data in a structured and organized manner, preferably in databases. Ensure regular backups, both on physical hard drives and cloud storage platforms. Protect the data against accidental deletions, hardware failures, and data corruption. Implement data access permissions to maintain data integrity.
10. **Collaboration and Data Sharing:** While maintaining the privacy and security of sensitive information, strive for open data sharing. Making datasets available to the wider research community can foster collaboration, leading to richer insights and more robust analyses. Ensure you adhere to legal and institutional guidelines when sharing data.
11. **Integrate Data Sets:** For a comprehensive understanding of an ecosystem, integrate elevation data with other relevant datasets, like vegetation cover, soil characteristics, or water quality parameters. This integration helps elucidate the interplay between different environmental factors and provides a more nuanced understanding of habitat dynamics.
12. **Stay Updated:** Technology and methods in the domain of GPS and elevation monitoring evolve rapidly. Ensure you're updated about the latest advancements, techniques, and best practices. Regular training sessions, workshops, or conferences can be beneficial.
13. **Coordinate and Project:** Use a consistent coordinate system and projection for all elevation data. This ensures spatial accuracy and compatibility when the data is analyzed, mapped, or integrated with other spatial datasets. For instance, using UTM (Universal Transverse Mercator) coordinates can ensure accurate distance and area measurements. Additionally, use consistent units (ft vs meters) and be sure all of these metadata are clear when sharing these data with others.
14. **Data Visualization:** Utilizing software platforms like GIS (Geographic Information System) or data visualization tools like Tableau, visually represent elevation data. Visual representations, like heatmaps or contour plots, can communicate complex data patterns in an intuitive manner, aiding stakeholders in decision-making. Ensure legends, scales, and annotations are clear and concise.

By following these best practices, organizations can guarantee the reliable, accurate, and efficient collection and sharing of RTK GPS elevation data, significantly enhancing the impact of conservation and restoration projects.

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4.2 Monitoring Sediment Accretion and Erosion

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Background

Since the establishment of the protocols by Roegner et al. in 2009, sediment accretion and erosion monitoring have emerged as essential tools for assessing the evolution and vitality of wetland habitats, particularly following restoration initiatives. This monitoring not only provides a lens into the transformative dynamics of wetland environments but also serves as a critical yardstick for evaluating how effectively sites are recuperating post-restoration and whether they're equipped to handle challenges such as potential sea-level rise.

The comprehensive long-term monitoring efforts executed through the Ecosystem Monitoring Program (EMP) and the Action Effectiveness Monitoring and Research Program (AEMR) have further underscored the importance of this monitoring. With over a decade of systematic observation and data accumulation since the initial Roegner protocols, the EMP/AEMR programs have presented invaluable insights into the intricate dance of sediment dynamics across varying wetland sites. One of the pivotal learnings from these extended observations is the inherent variability of sediment movement within sites. This natural variability, though initially not anticipated to be as pronounced, now necessitates a more exhaustive and granular monitoring approach.

Why Monitor Sediment Accretion/Erosion:

- **Insight into Restoration Dynamics**: Monitoring enables a deep dive into the restoration of natural sediment dynamics in wetlands. As restoration projects breathe life back into these ecosystems, it's essential to measure how these habitats evolve in terms of sediment deposition and displacement.
- **Adapting to Changing Climates**: With rising sea levels looming as a tangible threat, assessing how wetland sites are adapting becomes crucial. Monitoring sediment dynamics offers a snapshot of whether these habitats can withstand and evolve in the face of sea-level rise.
- **Understanding Sediment Variability**: The dynamic and often unpredictable nature of sediment accretion/erosion patterns makes regular monitoring vital. The EMP's findings have accentuated the importance of accounting for this variability. Such nuances emphasize that single-point observations or sparse monitoring systems may not paint the full picture.

The Need for More Granular Monitoring

As we've gained insights since the 2009 Roegner protocol, it becomes increasingly clear that our monitoring methods must evolve to capture the intricate dynamics of sediment accretion and erosion in wetlands more effectively. While the Roegner protocol initially recommended 1 or 2 sediment benches, our experience and the data's inherent variability suggest that this may not be sufficient for all sites or research objectives.

Base Recommendation for Sediment Benches

In light of our learnings and the observed variability across sites, a more granular approach to monitoring is not just preferable, but essential. When embarking on new restoration projects, the discussion about sediment dynamics should take precedence. If accretion and erosion dynamics are

deemed pivotal to monitor post-restoration, the installation of sediment and erosion pins should reflect this significance. As a baseline recommendation, there should be no less than 9 sediment and erosion pins across the area of interest, with a minimum of 3 replicate benches in each elevation zone. This arrangement ensures a comprehensive capture of the site's sedimentary dynamics, catering to its natural variability.

Considering a Power Analysis

For those familiar or willing to explore deeper statistical methodologies, a power analysis can be an invaluable tool. In this context, a power analysis involves statistically estimating the number of sediment benches required to detect a specific change or difference in sediment accretion and erosion rates with a given level of confidence. By considering the expected variability, desired effect size (e.g., detectable change in sediment levels), and the significance level, a power analysis can guide researchers in optimizing their monitoring setup to achieve meaningful results with minimal resource expenditure. However, we recognize that not everyone is well-acquainted with this statistical approach. While it's a powerful tool, our primary emphasis remains on the need for a more extensive network of sediment benches.

Concluding Thoughts

As we push forward in our mission to understand and restore wetlands, it's essential that our methodologies remain dynamic, adaptive, and robust. Ensuring that we have a comprehensive monitoring setup, whether informed by base recommendations or enhanced with tools like power analysis, guarantees that our efforts yield meaningful, actionable insights for the betterment of our estuarine ecosystems.

Objective

Estuarine environments are increasingly impacted by human activities and climate change. Monitoring sediment dynamics is crucial for assessing the success and sustainability of hydrologic restoration projects in tidal restoration sites. These sediment changes influence marsh surface elevation and, subsequently, plant communities, as plant species vary in sediment and water level preferences. Sediment accretion and erosion pins offer a cost-effective and accurate method to track these changes across different vegetation communities and elevations. Their accuracy, on par with advanced Sediment Tables (Nolte et al. 2012) when installed and monitored with care, ensures reliable data. The pins are also adaptable for monitoring in areas affected by geological events like tectonic uplift.

Regular monitoring of sediment dynamics using these pins aids stakeholders in decision-making related to restoration, infrastructure, and conservation. It also supports predictive modeling of these habitats in light of future challenges.

Factors Influencing Sediment Accretion/Elevation in Tidal Wetlands:

- **Topography:** This involves aspects such as the site's elevation and its relative position from the main tidal channel. Such factors dictate the flow and deposition patterns of sediments.
- **Hydrology:** Hydrological attributes like the frequency, depth, and velocity of tidal floods influence sediment carry and deposition rates. Sites with more frequent or deeper floods might experience different sediment dynamics than those with infrequent or shallower floods.

- **Vegetation and Soil:** The type of vegetation, its coverage, and the properties of the underlying soil significantly influence sediment capture and retention. Factors like soil texture, compactness, and organic content play crucial roles in sediment dynamics.
- **Disturbance:** Both natural and anthropogenic disturbances can cause abrupt changes in sediment levels. This includes events like storms, human activities, or animal interactions — each capable of redistributing or exposing sediments.
- **Tectonic Uplift:** This geologic process leads to an increase in land elevation due to tectonic forces. In regions like the Columbia River Estuary, where tectonic activities are pronounced, uplift can change the topography, influencing sediment deposition patterns.
- **Subsidence:** A decrease in land elevation can occur from various factors, including tectonic activities, sediment compaction, or even human activities like groundwater extraction. Subsidence can alter the way sediments are deposited and eroded, and in tidal wetlands, even minor changes in elevation can lead to significant shifts in sediment dynamics.
- **Sediment Availability:** The quantity and quality of sediment entering or leaving a site can determine its accretion and erosion rates. Often linked to broader watershed activities, sediment availability needs to be understood in that larger context.

Considering these factors holistically will provide a more comprehensive understanding of sediment dynamics in tidal wetlands, ensuring accurate monitoring and effective restoration strategies.

Materials

- 1-inch conduit pipe(s), cut into 4-6ft sections
- Mallet
- Level (at least 120 cm for precise measurements)
- Two-meter sticks or bendable rulers
- Compass
- Write-in-the-rain datasheet or notebook
- Pencil
- Design Plans
- RTK/GPS Unit

Method

We've published a presentation on this method update online, and it has helpful images. We recommend reviewing this in addition to reading the method details below. Presentation can be found here: Kidd et al. 2019. Revisiting Monitoring Protocols for Wetland Restoration. Science Work Group Presentation. Link

Location Selection

- Set sediment accretion pins along the site's elevational gradient, ensuring both low and high marsh areas are represented.
- The number of pin sets required will depend on site size, post-restoration accessibility, and site complexity.

Install

- Using a mallet, drive pins at least two feet into the ground. Regularly check with a level to ensure they are vertically aligned.

- Aim for the second pin to be approximately 100 cm from the first. If pins are not perfectly straight, adjust the distance accordingly.
- To ensure consistent spacing between pins, use a meter stick as a guide between them.
- Once both pins are nearly vertically aligned, place a level on top to ensure they are horizontally level as well.

Data Collection

- Using an RTK, survey both pins for X, Y, and Z coordinates.
- Document the coordinates, the orientation of the pins (e.g., east-west), and the side on which measurements were taken (e.g., north or south side).
- To measure: Begin at one pin and measure all four cardinal directions from the ground surface to its top using a folding meter stick. Repeat for the other pin.
- Place a level or second meter stick on the pin tops. Ensure any lip on the level doesn't extend below the pin tops. Set the instrument so that you can measure in 10 cm intervals between the pins.
- Place another meter stick directly on the ground, clearing any vegetation to measure from the true substrate surface. Avoid pressing into the substrate.
- At eye level to the instrument's top, measure every 10 cm between the pins, from 0 cm to 100 cm or beyond if the pins are set closer than 100 cm apart.
- To monitor for disturbances, always RTK the tops of PVC Sed Pins. If installed correctly, these elevations should remain consistent. However, disturbances can cause them to shift.
- Frequency of data collection should be dictated by the research questions specifically to the project being monitored, we recommend winter and summer (approximately every 6 months) monitoring coinciding with other field tasks such as channel cross-section monitoring, photo point monitoring, and data logger maintenance.

Considerations

- Due to potential disruptions from drifting woody debris in tidal wetlands, especially during high-water winter months, consider installing extra pin sets as backups against wildlife or debris damage.
- Ideally, pins should capture the full gradient: low, mid, and high marsh. Installing three sets of pins (three pins per set) is recommended, resulting in at least nine pins per site.

Data Management and Analysis

Data Format

For optimal analysis, sediment accretion data should be stored in a long format as illustrated in Table 8. This approach not only simplifies the data structure but also ensures that each measurement date is captured as a unique record.

Table 8: Suggested Sediment Accretion data warehouse format

Site Name	Stake Name	Date of measurement	Pin	Distance or Direction	Height from Ground to Level

Potential Analysis Methods

1. **Annual Elevation Change and Accretion/Erosion Rates:** Calculate sediment gain or loss over specific periods by subtracting year-to-year measurements. This captures the dynamic shifts in sediment dynamics, useful for monitoring annual trends and variations.
2. **Net Normalized Elevation Change and Accretion/Erosion Rates:** For a holistic view, subtract all monitoring data from the initial measurements. This approach offers insights into sediment changes across the entire lifecycle of a stake or project, revealing overarching trends and patterns.
3. **Comparative Analysis with Sea Level Rise:** Assessing sediment accretion rates against sea level rise projections can help quantify the overall balance of wetland elevation gain or loss. Such an analysis is vital in forecasting wetland resilience against future environmental challenges. This relationship is depicted in Figure 17, showing a comparative trend between forecasted sea level rise and the average sediment accretion rate across the EMP sites.
4. **Soil Carbon/Methane Sequestration:** Through soil cores (see section 5.5), assess the rate of carbon and methane sequestration. This provides deeper insights into the wetland's role in climate change mitigation.

Recommendations for Comprehensive Data Collection

- Ensure sediment benches are installed across varied elevation gradients.
- Consistently record elevations of Sed Bench PVC pins to maintain data accuracy.
- Document the dominant species' vegetation cover and monitor soil parameters on-site.
- Regularly capture photographs of sediment benches and their immediate surroundings to maintain a visual record, aiding in qualitative assessments.

Alternative Monitoring Methods

While sediment accretion pins provide valuable data, other effective monitoring methods include:

- **SET (Sediment Elevation Tables):** A precision tool used to measure very small changes in elevation over time. Comprising a fixed benchmark and a portable measuring device, it provides data on whether the ground is rising or falling, thus offering insights into sediment accretion or erosion.
- **Marker Horizons:** This method involves placing a thin layer of identifiable material (often feldspar clay) on the sediment surface. Over time, sediment that accumulates over this layer can be measured, offering a clear picture of accretion rates.
- **Sediment Plates:** These are flat plates placed at the marsh surface that capture newly deposited sediments. By measuring the thickness of sediment on these plates over time, accretion rates can be determined.
- **UAV-based Surface Monitoring:** Using Unmanned Aerial Vehicles (UAVs or drones), this method captures high-resolution imagery of the site. Through repeated surveys, changes in the landscape can be analyzed, and sediment dynamics can be inferred by observing features such as sediment deposits, erosional patterns, and vegetation changes.

Incorporating a diverse array of monitoring techniques provides a more comprehensive understanding of sediment dynamics. In the below reference and resource section we have provided further reading for anyone who is interested in exploring these additional methods. As tidal wetlands face multifaceted challenges, understanding these dynamics becomes crucial, from guiding restoration efforts to ensuring the long-term sustainability of these critical ecosystems.

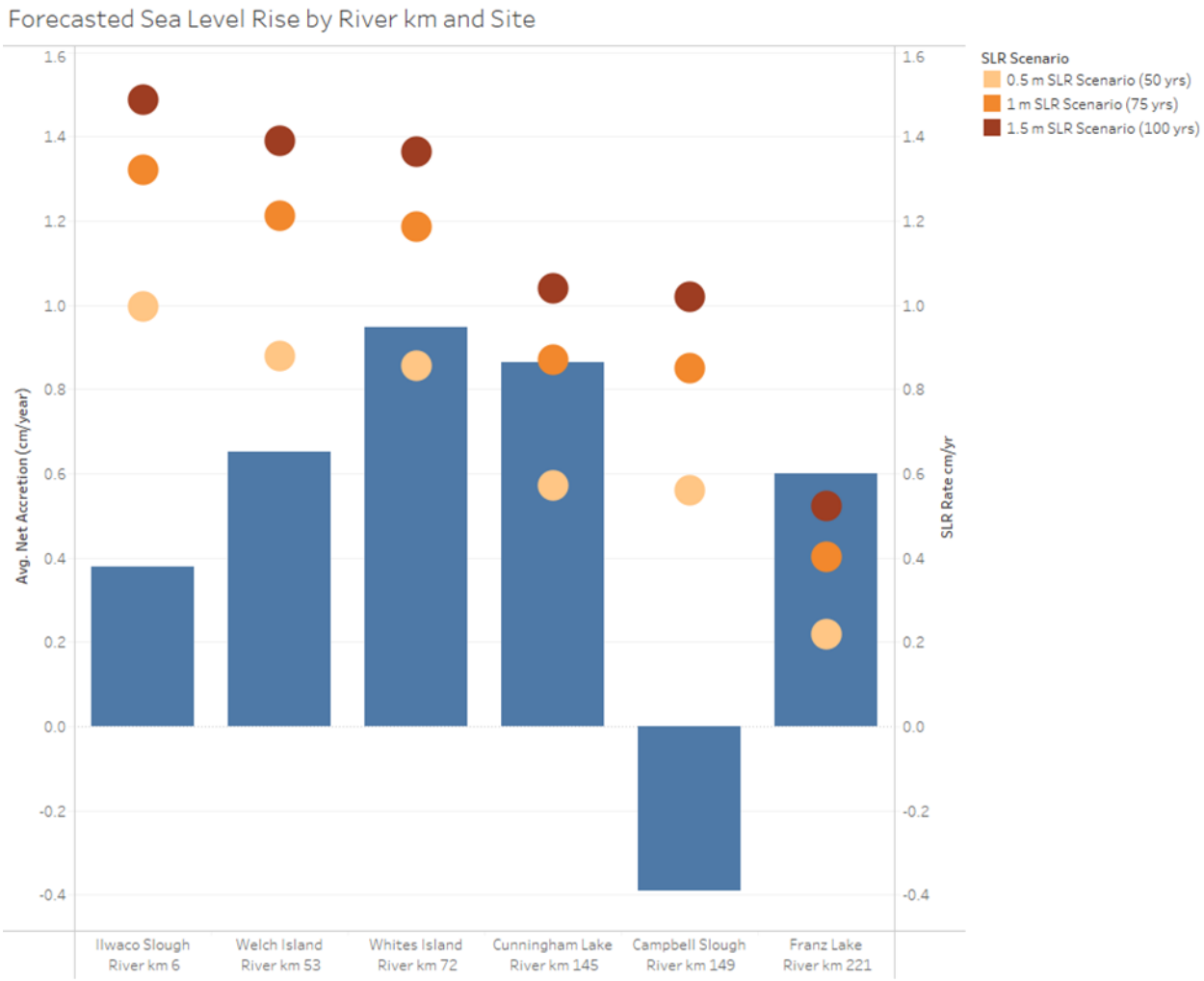

Figure 17: Forecasted Sea Level Rise and average rate of sediment accretion for the EMP Sites. Taken from Kidd et al (2023).

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4.3 Channel Cross Sections and Flow Monitoring

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Background

Channel cross section monitoring has long been instrumental in capturing geomorphological transformations within tidal channels. The methodologies delineated here have evolved from collective discussions and experiences since the publication of the 2009 protocols by Roegner et al. Our approach integrates the contributions and insights of the Columbia Land Trust, The Lower Columbia Estuary Partnership, the Columbia River Estuary Study Taskforce, and others. These collaborative refinements reflect the field's advancements and the broader understanding of tidal channel dynamics.

Derived from these collective wisdoms, these methodologies enable the capture of geomorphological changes over time within tidal channels. Observing how tidal sloughs, with their diverse substrates, adapt to tidal hydrology reconnections is essential for sound project design. Moreover, combining this data with water surface elevation readings allows for a deeper understanding. For instance, when channel bottom elevation measurements are paired with water surface data, we can calculate habitat opportunity for species like juvenile salmon. Additionally, these measurements facilitate the gauging of the organic material flux that wetlands contribute to the expansive river ecosystem.

While the use of an RTK for surveying is recommended due to its precision, there are instances where its deployment might not be feasible. In such cases, an auto-level, periodically calibrated with a surveyed benchmark, serves as a valuable alternative.

It's crucial to note that safety is paramount. Tidal channels can develop extensive mud depths, making traversing them not only challenging but potentially hazardous. If conditions are deemed unsafe due to deep mud or other factors, alternative methods for cross section monitoring should be employed. Ensuring the well-being of the monitoring personnel should always be the top priority.

Objective

Channel cross-sections are crucial tools in geomorphological studies, providing essential data on channel morphology - the shape and structure of the channel. Through cross-sections, researchers can track changes in the marsh surface elevation adjacent to the channel. Such observations offer insights into how tidal forces, sediment deposition, and other environmental factors alter channel shapes over time.

Furthermore, when these channel morphological data are combined with water surface elevation measurements and flow data, a comprehensive picture emerges. This combination aids in understanding tidal habitats – regions inundated by tides – and the movement of organic materials through the channel. Capturing flow measurements in tandem with cross-sections allows for a better understanding of how water movement shapes the channel and influences sediment transport.

Another functional advantage of channel cross-sections is their potential use as markers for photo points. This multifunctionality streamlines the monitoring process, consolidating monitoring locations.

However, care should be taken when designating sampling points; sediment accretion sites or vegetation sampling areas should be distanced from other metrics to avoid disturbance or trampling.

Materials

- **100-meter measuring tape(s):** For accurately measuring distances across the channel.
- **Stadia rod:** A graduated rod used with a leveling instrument to determine differences in elevation.
- **RTK or Auto-level:** Surveying instruments providing high precision elevation data.
- **Flow Meter:** An instrument to measure the flow rate or quantity of a gas or liquid moving through a pipe.
- **Metal T-posts:** Sturdy metal posts for marking and measuring.
- **Mallet or post-pounder:** Tools for driving the T-posts securely into the ground.
- **Write-in-the-rain data sheet or notebook:** Ensures data is recorded even in wet conditions.

Location Selection

When selecting a location for monitoring, certain features are desirable:

- **Smooth Flow:** Areas where the water flows smoothly, without abrupt changes in direction or speed.
- **Minimal Obstructions:** Regions devoid of large obstructions that can skew measurements.
- **Parallel Flow:** Locations where the flow is parallel to the stream banks, offering a uniform cross-sectional view.
- **Proximity to Data Loggers:** Being near a Water Surface Elevation (WSE) and Temperature logger can be advantageous, enhancing the data's depth and modeling capabilities.

It's recommended to monitor cross-sections at both the input (where water enters) and the outgoing sloughs (channels through a swamp or marsh). Essentially, any section of the channel, where understanding its evolution or stability is of interest, should be part of the study.

Measuring the cross section:

Capturing the intricacies of a channel requires methodical measurements. Cross-sections should extend from one bank to the other, ideally encapsulating the adjacent marsh surface elevation. The use of T-posts as end markers ensures a consistent reference point for measurements year after year. Once securely placed, a taut tape between the markers provides a reference line. With this setup, the channel's profile can be surveyed with an RTK, capturing both depth and water surface elevation.

Given the natural variability of channels, there's no one-size-fits-all approach to measurement intervals. However, the chosen methodology should be consistent to allow for comparative studies across years.

Measuring the flow rate:

Measuring the flow rate: To adequately capture the dynamic movement of water within tidal channels, flow rate measurements should mirror the care taken with channel cross-sections.

Location Consistency: Flow rate measurements should be aligned with cross-sectional measurements to ensure congruency in data. This way, the relationship between channel morphology and water flow can be better understood. Moreover, consistent location selection reduces variability in data caused by site-specific factors.

Sensor Positioning: The flow meter's sensor should face upstream to accurately gauge the oncoming water's velocity. This positioning reduces potential turbulence-induced errors in flow rate readings.

Depth Consideration: To obtain a representative flow rate measurement, it's recommended to position the sensor at a depth of approximately 60% of the total water column. This places it 40% above the substrate (Figure 18, USU 2018). The rationale behind this depth is that it often captures the average velocity in many riverine and estuarine systems, considering the slower flow near the substrate due to friction and potentially faster flow near the surface.

Measurement Points: For each cross-section, define intervals or polygons where flow measurements will be taken. To ensure thorough understanding of flow variability, measurements should be made at the midpoint of these intervals along the tape measure. Use the following guidelines for measurement intervals, but remember, these are general suggestions (USU 2018) that can be adjusted based on specific research needs:

- For channels less than 3 meters wide, take measurements every 0.15 meters, starting the first reading 0.075 meters from the edge.
- For channels wider than 3 meters, divide the width into 20 evenly spaced intervals and take measurements at each division. The first measurement should be taken half of one interval's distance from the edge.

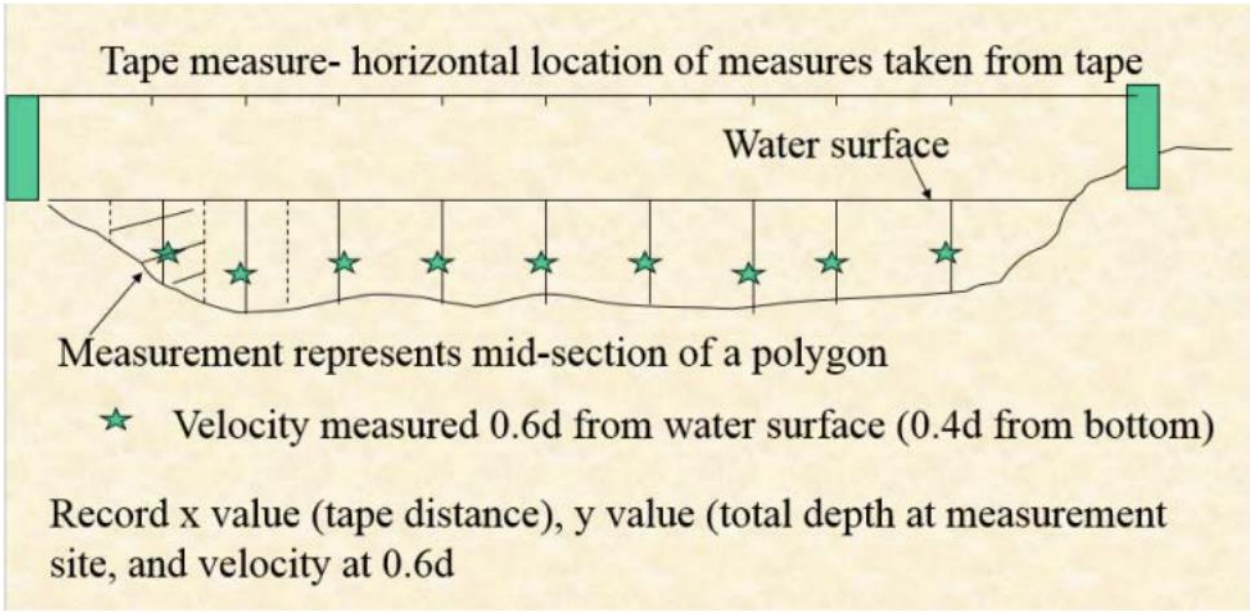

Figure 18: Flow meter measurement locations; from USU 2018.

Data Management and Analysis

Data Management:
Cross-section data should ideally be stored in a long format, as depicted in Table 9. If an RTK was utilized, points can be imported into a GIS platform. The measure tool can then be employed to ensure the consistency of distances between points across years.

Table 9: Cross-section data field data recording suggestion.

Cross-section Name	Date	Time	X distance	Elevation of Ground	Water Depth	Velocity

Analyzing Cross-section Data:

- **Channel Morphology Over Time:** Track geomorphological shifts by comparing annual data. This can reveal patterns such as channel widening, deepening, or sediment deposition.
- **Flow Velocity and Volume:** By juxtaposing cross-sectional data with flow measurements, estimates of flow velocity and volume can be generated. This is essential for evaluating hydrodynamic goals post-restoration.
- **Channel Stability and Erosion:** By periodically assessing the channel's edges, changes due to erosion or sediment deposition can be identified.

Salmonid Habitat Opportunity:

Marrying water surface elevation data with cross-sectional data facilitates depth analyses, vital for understanding salmon access opportunities. This assumes that salmonids require a minimum depth of 0.5 m to access and utilize the channel of wetland, adding additional layers of data such as water temperature can enhance this analysis further (Kidd et al. 2023, Bottom et al. 2003).

Discharge and Hydrology Models:

Integrating flow data with cross-sectional data aids in determining discharge, a metric fundamental for hydrology models like HECRAS. Additionally, tracking the temperature differential from the input stream to the outgoing slough can provide insights into the thermal load, further enriching model data.

Rating Curve and Continuous Discharge Monitoring:

Combining the physical cross section, water depth monitoring, and flow rates, a rating curve can be established, allowing for continuous discharge monitoring. Establishing this curve demands intensive flow rate monitoring across varied conditions, which may not always be feasible (USGS 2023).

Recommendations for Comprehensive Channel Monitoring:

- **Periodic Surveys:** Implement regular channel surveys to chronicle changes, we recommend annual surveys during low water conditions, or more frequent depending on the research objectives or regulatory requirements.
- **Flow Measurements:** Deploy flow meters or equivalent tools for insights into the channel's hydrodynamic behavior.
- **Photographic Records:** Establish a visual timeline through consistent photographic documentation.
- **Vegetation Monitoring:** Keep tabs on the surrounding vegetation, as it plays a role in channel morphology.
- **Water Quality Probes:** Measure parameters like water depth, salinity, temperature, or dissolved oxygen, crucial for certain habitats or species.

Alternative Monitoring Techniques:

- **Lidar Surveys:** An airborne method offering detailed topographical data. Especially valuable for expansive sites or those with access constraints.

- **Acoustic Doppler Current Profilers (ADCP):** Useful for gauging water flow velocities over extended periods.

In tidal wetland settings, monitoring channel cross sections and water flow conditions is pivotal for both restoration success and the long-term vitality of these environments. By integrating insights from these methods with other monitoring tools, stakeholders can craft a detailed understanding of these ever-changing ecosystems, informing both conservation and restoration strategies.

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5. Wetland Plant Community and Soil Conditions Monitoring

5.1 Plant Community Monitoring for Tracking Detailed Plant Species Composition

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Background

In the context of wetland plant community monitoring, our methodologies have traditionally bifurcated into two distinct approaches. Within the Action Effectiveness Monitoring and Research (AEMR) sites, we've favored a grid-based monitoring strategy. This entails setting up a grid of shorter transects, usually around 50 meters long, across a predefined area of the restoration site. This method has provided invaluable insights into the intricate dynamics of restoration sites.

Advantages of Grid-Based Monitoring:

1. **Spatial Precision:** By focusing on specific restoration effects within a bounded region, grid-based monitoring provides an unparalleled spatial resolution, enabling detailed evaluations of shifts in plant species composition and soil conditions.
2. **Comparative Analysis:** This methodology supports direct juxtapositions between affected and unaffected areas within a restoration site, revealing nuanced differences and shedding light on localized ecological reactions.

In contrast, an alternative method employs extended, strategic transects spanning the larger sections of a site. These can be hundreds of meters long, traversing diverse elevations and conditions, with its own set of benefits.

Advantages of Extended Transect Monitoring:

1. **Comprehensive Site Assessment:** Extended transects give a panoramic view of the restoration site, accounting for varied terrain and habitats, thereby painting a full picture of the site's reaction to restoration endeavors.
2. **Long-Range Impact Assessment:** Assessing at intervals between 0-5 meters over the long span of the transects reveals widespread impacts, showcasing trends that might be missed by grid-based methods.

The Ecosystem Monitoring Program (EMP), meanwhile, adopts a hybrid methodology combining elements of both the aforementioned approaches. EMP sites, which make up a substantial portion of our reference sites within the estuaries, are meticulously monitored via this hybrid technique. Essentially, the choice of monitoring approach should align with the specific objectives of the research site and should be replicable when appropriate. Subsequent sections will delve deeper into these monitoring methodologies employed by the Ecosystem Monitoring and Action Effectiveness Monitoring and Research Programs.

Objective

Building upon the foundational Roegner et al. protocols from 2009, our expanded focus encompasses herbaceous plant community monitoring across various conservation and restoration initiatives, including but not limited to the CEERP. Recognizing that augmenting the proportion and diversity of native plant species is paramount for juvenile salmon habitat restoration, our approach is not only relevant to CEERP projects but also to a broader range of ecological restoration efforts. This includes a critical examination of the impacts of invasive species on wetland ecology and young salmon, where insights such as those from Johnson et al. (2018) are integral. Employing vegetation transects and grids, our methodology serves as a robust metric for differentiating between native and non-native plant species in both treatment and control areas, applicable across diverse environmental contexts.

Materials

- 100-meter measuring tape(s)
- Plastic camping stakes
- Zip ties
- Write in the rain data sheet
- Pencil
- Sharpie
- Plant ID books
- Sample bags
- Clipboard
- 1m^2 quadrats
- Relevant plant guides and species lists (e.g., Hitchcock and Cronquist 1973, Guard 1995, Cooke 1997)

Figure 19. Vegetation plot and transect.

Methods

Overall Approach to Estimating Plant Cover and Species Diversity

In order to assess plant cover and species diversity along each transect, follow this systematic approach:

- **Transect Setup:** As discussed in the background section, transect location, number and placement within a site should be determined based on the needs of the study. Generally, when establishing vegetative transects the number of transects fall within the range of 3 to 5 transects per site, however this can vary depending on monitoring goals and the variability of the conditions on the site. These transects can range from 5 to 300 meters in length. The specific length and number of transects and quadrats established and surveyed on each site should be informed by research objectives and guided by the principle of capturing the plant species diversity effectively. It is common practice to continue adding transects and quadrats until no new plant species are encountered, ensuring comprehensive coverage of the site's vegetation composition.
- **Timing:** Conduct the plant monitoring during the summer months, typically in July and August when vegetation is at its peak growth.
- **Transect Placement**: Randomly position these transects within the site area that has been selected for monitoring, ensuring they run parallel to the tidal wetland elevation gradient. This randomization helps capture a representative sample of the site's vegetation.

- **Assessment Intervals:** Along each transect, evaluate vegetative percent cover at regular intervals, which can range from 1 to 10 meters. When deciding on the interval distance, take into account the size of the marsh and the consistency of its vegetation. While the starting point should ideally be generated randomly, the specifics of the study might dictate otherwise. It's worth noting that in the history of the AEMR grids, some quadrat sample locations along transects underwent annual randomization. Given the limited number of plots sampled per site, this method introduced additional variability into the data, complicating the tracking of changes over time. To address this challenge and streamline the monitoring process, we began resampling the same (initially randomized) plots annually starting in 2020. This change aimed to decrease data variability and improve our ability to monitor temporal changes.
- **Quadrat Placement:** At each interval on the transect tape, place a 1 m^2 quadrat on the substrate. This quadrat provides a defined area for estimating percent cover.
- **Percent Cover Estimation:** Plant cover data collection is a specialized skill requiring extensive plant species identification knowledge, even a trained wetland botanist should work closely with a seasoned field plant community surveyor to ensure their data is representative. If there are two or more data collectors, it's essential to calibrate their observations to ensure consistency, make sure all surveyors are in agreement on how survey data is collected and if/how living vs. dead species are recorded as well as detritus vs. litter, notes like these will be critical for consistency.

    - Use 5% increments to record the coverage, ranging from 0% (indicating no coverage) to 100% (indicating complete coverage). It's important to note that in each quadrat, the total percent cover should always sum up to 100% or more. This accounts for the presence of non-vegetated features like bare ground or open water, which should be included in the percent cover estimations alongside vegetation, if they are visible within the plot prior to moving the vegetation for further analysis.
    - To ensure accurate estimations, follow a two-step process. Begin by assessing factors such as bare ground or open water. Record their percentage cover separately before examining and estimating the plant coverage. This practice helps prevent overestimation of these features once vegetation is moved or disturbed to inspect for additional coverage.
    - In this process, each element (plants, bare ground, open water) has its own percent cover recorded, allowing for a more precise assessment of the overall vegetation cover while acknowledging the presence of substrate elements like, debris, bare ground, or open water. For example, in plots with layered and dense vegetation, the estimation might exceed 100%.
    - Furthermore, adhere to the guideline that any species with a cover less than 5% should be recorded as 1%. This approach guarantees that even minor contributors to the overall vegetation cover are accounted for in the data, ensuring precision in assessing plant community composition.

- **Species Identification:** When collecting field data and for long-term database consistency it is recommended that the shorthand for scientific plant names (i.e. plant codes provided by the NRCS USDA Plants database) are used. These codes are standardized and widely accepted within the scientific community. This approach maintains consistency and avoids redundancy. If specific USDA codes are not known while in the field, then the data collector should make a note of the full scientific name on the data sheet for later abbreviation. Additionally, native, non-

native and wetland indicator status determination for each plant species should be identified using the online NRCS PLANTS database (http://plants.usda.gov). If plant status is ambiguous, it was listed as unknown for analysis purposes.

- **Additional Features:** As mentioned above, in addition to vegetative cover, note the presence of other features such as bare ground, open water, wood, detritus, and drift wrack, etc. within the quadrat. Other notes such as grazed by cattle and the % of the quadrant grazed can be helpful for later data interpretation.
- **Specimen Collection**: If plant identification cannot be determined in the field, collect a specimen for later identification in the laboratory using taxonomic keys or manuals.
- **Unidentified Entries:** In cases where an accurate identification cannot be resolved (in the field or lab), label the plant as "unidentified" within the database. Adding notes to this can also help with later-reclassification, such as describing the species characteristics, basic growth form (grass, herb, tree, shrub), living or dead, photos of the specimen, and when and where it was found can be helpful.
- **Further helpful tips:** When conducting long-term studies, it can be helpful to **c**arrying copies of the previous years' plant data along with the survey team, this can also help ensure the transect and quadrant locations are correct, as things like large shrubs do not shift dramatically from year to year and can be used to check and ensure transect and quadrants are realigned properly before surveys take place.

As part of this monitoring approach, focus on these key parameters:

- **Species Richness:** Assess the number of plant species present within each quadrat. Keep track of this metric as you progress along the transect.
- **Height Measurements:** Record the height of plant species where applicable and relevant to your study objectives.
- **Relative Cover Calculation:** Calculate the relative cover for each plant species within the quadrat. This can be done by dividing the estimated cover of each species by the total cover recorded for all species in that quadrant and multiplying by 100.
- **Diversity Indices:** Utilize standard methods, as outlined by Magurran (1988), to calculate diversity indices such as Shannon diversity and evenness from the relative plant cover data.

By following these systematic steps and parameters, you can effectively estimate plant cover and species diversity along your transects, providing valuable insights into the vegetation composition of your monitoring sites.

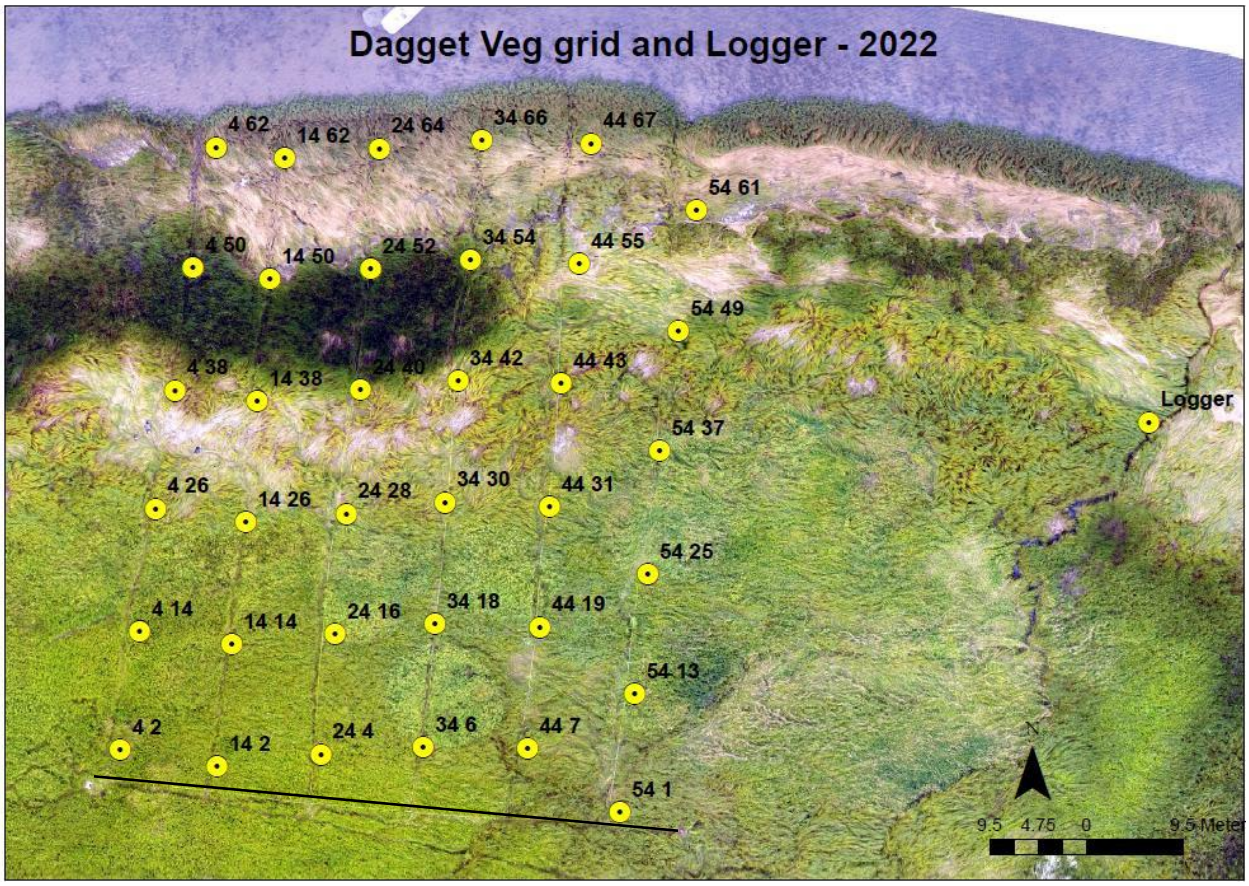

Figure 20: A map of Dagget Point showing the base line and vegetation grids.

Data Management and Analysis

The core purpose of this protocol is to provide a consistent and comprehensive approach for storing, preparing, and analyzing vast vegetation datasets.

Data Storage Protocol: Data storage serves as the foundational pillar of our methodology. We prioritize clarity and accessibility in our approach. By organizing data into wide tables where each column captures distinct vegetation attributes—such as species, height, age, or coverage percentage—we ensure both depth and ease in navigation. Periodic reviews of these table structures bolster our adaptability to evolving data landscapes. The unionization technique further fortifies our framework by consolidating related data tables. Through meticulous alignment and vertical concatenation, we weave together diverse datasets to offer a holistic viewpoint.

Data Preparation Protocol: Tableau Prep is our linchpin in the data preparation phase. Seamlessly integrated into our data workflow, it primes data for the subsequent analysis. Harnessing its functionalities, we clean, reshape, and merge datasets. Keeping abreast of Tableau Prep's evolving features ensures we leverage its full potential. As we navigate through its interface, discrepancies often come to the fore. Addressing such anomalies—whether inconsistencies, outliers, or missing values—is pivotal. The path forward may involve imputation, outlier correction, or exclusion, depending on the nature of the issue. A salient aspect of this stage is merging diverse datasets. With Tableau Prep's advanced tools, this integration ensures consistency while upholding the integrity of our data.

Analysis Considerations: Venturing into the realm of analysis, co-locating vegetation data with auxiliary datasets, such as water depth (or duration of flooding), elevation, and soil conditions, is crucial. This enriched juxtaposition facilitates a detailed site-by-site evaluation. The outcome is not just an insight into the shifts in plant community dynamics but, more critically, an understanding of the mechanisms underpinning these changes.

A noteworthy mention here is the potential for pseudo-replication inherent to transect-based data collection. Such a setup might inadvertently lead to non-independent measurements, especially with closely spaced measurements or transects. The ramifications of pseudo-replication are closely tied to the research questions posed and the subsequent interpretation of data. For broad pattern evaluations, closely spaced measurements might be considered independent; however, for more granular inferences, it's a significant concern. Thus, during analysis, it's crucial to employ statistical methodologies that respect the inherent structure of the data. Transparency in reporting and discernment of the spatial data structure are essential to derive robust conclusions.

Subsequent sections of this protocol will provide deeper insights into the integration and analysis of these co-located data types.

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5.2 Plant Community Monitoring for Ground Control Points and Dominant Plant Species GIS Mapping

Authors and Editors: S. Kidd[1], S. Rao[1], I. Edgar[1]

[1] Lower Columbia Estuary Partnership

Background

Please refer to Chapter 2.2 UAV Photography and Orthomosaics for these details. More detailed information on how to interpret drone imagery for analysis is under development as we refine these methods for publication. Please reach out to the authors directly if you have any questions.

5.3 Tracking Wetland Primary Production Through Aboveground Plant Biomass Collection

Authors and Editors: S. Kidd[1], I. Edgar[1], S. Rao[1], A. Silva[2]

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Background

Emergent wetland vegetation plays a pivotal role in understanding primary productivity within estuarine ecosystems. The Ecosystem Monitoring Program (EMP) embarked on its journey of cataloging aboveground plant biomass in 2011, under the foundational guidance of Amy Borde. Her pioneering efforts set the stage for what would become a continually evolving and refining methodology.

As the years progressed, our techniques incorporated new research paradigms. Notably, in 2017, the scope expanded to include detrital sampling, spotlighting the role of detrital production and export in the ecosystem. Further refinements up to 2021 emphasized detailed, species-specific biomass contributions across different marsh strata. Such adaptations not only heightened the granularity of our data but also ensured alignment with long-term comparative analyses.

The core structure for these biomass sampling methodologies derives from the Ecosystem Monitoring Program's Biomass and Detritus Sampling Procedures draft memo (Kidd, 2017). After Amy Borde's trailblazing contributions from 2011-2017, the baton was carried forward by LCEP in partnership with Roger Fuller (2017-2018) and Katrina Poppe (2017-2018), who enriched the process with their insights.

Objective

The overarching aim is to systematically collect, process, and analyze aboveground biomass from estuary ecosystems to understand the primary productivity of emergent wetland vegetation. This effort seeks to gauge the export of organic material from wetlands, especially macroinvertebrates and plant detritus, which significantly contributes to the food web of the larger Columbia River System. A meticulous assessment of variations in plant biomass during growth and dormancy phases provides key insights into this dynamic. By juxtaposing the acquired biomass data with other ecosystem parameters, we aim to unearth correlations that illuminate the intricate interplay of variables such as river discharge with plant biomass production, fostering a holistic understanding of estuarine dynamics.

Materials

- 1/10 m² PVC Quadrat.
- Heavy-duty garden shears and clippers for woody stems.
- Rite-in-the-rain data sheets and labels.
- Pencils and sharpies for marking.
- Gallon and quart-sized freezer Ziploc bags.
- Rubbermaid tote lid or heavy-duty plastic sheet for sorting.
- Plant ID guides.
- Cooler(s) for transportation.
- Optional gloves.

Methods

Field Data Collection

Biomass plots are often done in coordination with vegetation grid sampling, ensure biomass plots do not fall on or immediately near long-term percent cover vegetation monitoring plot and measures at least one meter away from transect line. In order to compare plant diversity and abundance at different elevations in a tidal wetland, five plots are completed in high marsh and five in the low marsh. Site specific conditions may require a different number of plots; tidal inundation limiting the sampling window with overbank flooding, and budget restrictions may necessitate fewer samples.

Biomass sampling is done within plots of 0.1 m^2 = 31.6 cm by 31.6 cm in size (Photos to the right).

Figure 21. Biomass plots before (left) and after (right) sampling.

Identify plot ID for data sheet and labels. Identify the two dominant species (percent cover), record these and their percentage and average height, and then record just the scientific names of all other observed species. Set out a large sheet of plastic, or tote lid, to set the sample on to facilitate separation prior to bagging. Prepare labels for bags prior to beginning collecting the sample; this helps ensure the right categories and species are being separated correctly.

The two dominant species will be bagged separately: separating the "Live" and "Dead" of the dominant species. All other species are divided into the "other" category, separated into "Live" and "Dead" sample bags. Multiple bags may be needed. Additionally, detrital samples should be separated as well.

To have consistency between sample plots and personnel the quadrat is anchored firmly, and the vegetation cut along the inside of the quadrat. The sides of the quadrat represent an invisible sample border vertically, collecting only what is inside the quadrat and not hanging outside the sample area. This reduces variability in the amount of vegetation that is pulled into the plot from rooted plants inside or immediately adjacent.

Belowground biomass should not be included in the sample; rhizomes may be present complicating categories used for analysis and collection. Prior to beginning collection, it should be decided, based on research goals and level of effort, how plants such as *Phalaris arundinaceae* (PHAR) that have roots, above ground rhizomes, attached standing dead, and live growth heavily mixed together will be divided into categories and what those categories will be. Bags should have rite in the rain labels located inside the bag that includes the site name, plot ID, date, time, and sampler initials. One should duplicate this information using permanent marker on the outside of the bag as well.

Continue clipping, sorting, and bagging vegetation until the plot is cleared. After sampling use a soil probe to record soil ORP, pH, Temp, Conductivity, and Salinity for each biomass sample plot. Wait up to several minutes for the soil ORP and pH to stabilize. Place these probes approx. 5 cm into the soil. Probes must be rinsed or cleaned with a wet cloth in between sample plots. Be sure to note the time and date of sampling and if (and how much) standing water within the plot.

Lab Analysis

Washing instructions:

1. Samples can be dried in paper lunch bags, so prepare some bags by labeling them as desired with a black sharpie.

2. Sort the sample bags and wash/process them in order, with all samples from a single plot done together as much as possible. Large samples requiring multiple bags are easier to track and combine if they are together. Otherwise, it's easy to forget to combine them later for sample analysis. Occasionally there are labeling errors on bags, or discrepancies between bags and field sheets, so it is helpful to process all samples from a plot together, and cross-check them against photocopies of the field datasheets. In addition, it is sometimes necessary to do a little more sorting among live/dead/detritus samples, so it's best to have all samples from a plot together, and to start with the live samples.

3. Sorting: Remember that we are trying to compare the C/N/Lignin values of live vs. dead vs. detritus samples. Part of the reason we do this is because species differ in terms of how much of their tissue nutrients (N in particular) they're able to remove from senescing tissue and pull back into their stems/roots. This affects the nutrient and food web value of the decomposing organic matter. (For example, one hypothesis is that PHAR might be better at removing N from its dying tissue before it enters the food web, yielding a lower quality detritus.)

   For this reason, it's important that as we process the samples, we check that the samples contain just live or dead or detritus and separate them if necessary. And we should check that the samples contain just the plants indicated on the field data sheet. Before processing an "Other" bag, check the species listed on the field sheet and pay attention to the sample as you wash it. Occasionally a bag is mislabeled, or sometimes has species that are missing from the field sheet in which case the field sheet may need to be edited.

   While collecting samples in the field it is often difficult to be as careful as necessary in separating dead/live/detritus. This is most relevant for large samples like live PHAR, JUEF or similar dominant rhizomatous or stoloniferous species which can often have live/dead mixed together. There isn't always time in the field, under the pressure of tidal windows, to sort the sheer volume of material from a dense PHAR or JUEF plot. Time spent sorting also varies among field crew members.

   For those reasons, during sample cleaning in the lab, we sometimes need to do some final sorting, particularly of "Live" samples. "Live" stems should include all green stems and stems that are partially green but may have begun to senesce and may also include stems that are mostly brown/dead if the stems were clearly alive during that growing season. They may also include brown leaves attached to live stems. For example, depending on the time of sampling, some species may have already set seed, and stems that were new that year may be starting to senesce already. Recently dead material is usually a light brown color. This should all be included in the "Live" sample.

However, stems that are dead all the way down to the stolon/rhizome should be separated into the "Dead" sample. Any stem that was dead prior to the current growth season should be separated into the "Dead" bag. These stems usually have more sediment adhered to them, are very weathered-looking, are not as stiff as recently-dead stems, and are colored grey-brown (rather than the light brown of recently dead stems) since they've overwintered.

PHAR stolons/rhizomes are often so dense that they may trap detritus (un-attached, soft, well-decayed organic matter) which is mixed into the live bag when they're cut. During processing this detritus should be separated and added to the detritus sample.

Again, remember that we're trying to detect C/N/Lignin differences between dead and live tissue, so it's important that the processed samples be carefully separated and that live samples aren't contaminated with detritus and old dead stems.

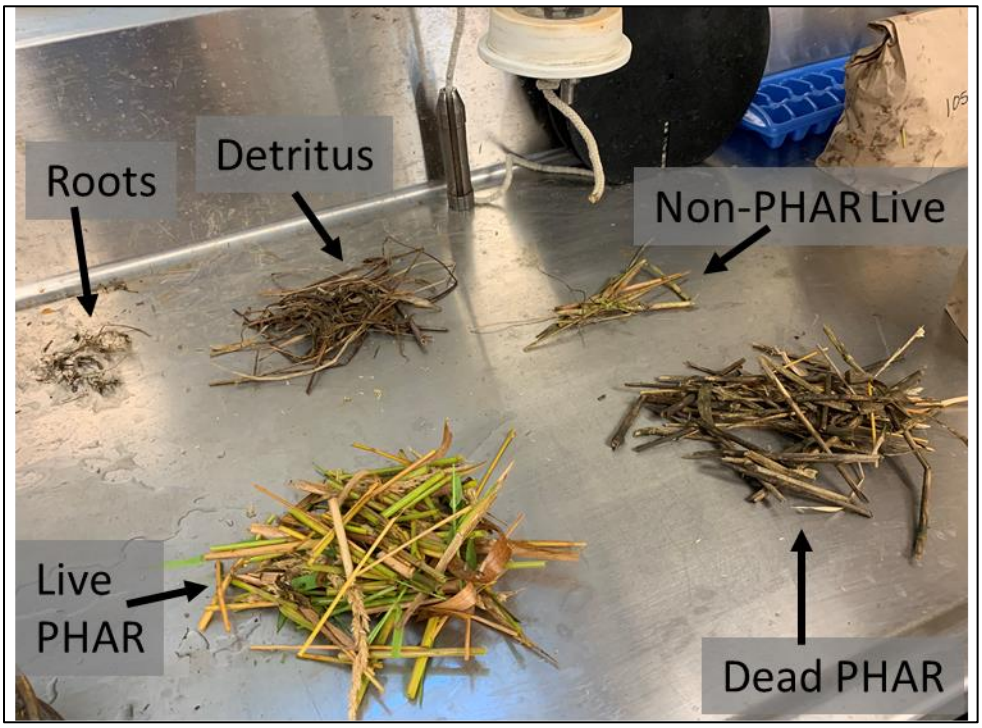

Figure 1. Example of a "Live PHAR" sample that has been sorted prior to washing. Some live material was not PHAR and was transferred to the "Other" bag. Old dead stem and leaf material that was coated with sediment and was weathered and grey colored was separated and transferred to the dead PHAR bag. Note that the remaining "Live PHAR" pile includes light-brown-colored dead stems and leaves that had recently senesced (i.e. they were new growth of the year that were beginning to senesce).

4. Winter stem identification: Sometimes winter stolon/rhizome samples are difficult to identify in the field. Watch for these as you sort/wash samples:
    a. *Polygonum hydropiperoides* (POHY) stems are black and dead-looking on the outside in winter, but maybe green/live on the inside, so check the cut ends carefully as you sort. Live stems also tend to be stiffer while dead ones tend to crush more easily

b. Dead *Myosotis* stems in winter can look like POHY sometimes because of black clasping leaf bases at nodes. POHY has stem-clasping stipules that turn black in winter.
c. PHAR-Dead and POHY stolon's/rhizomes can be confused in winter when stems of both can be blackish… POHY has stem-clasping stipules at nodes, and PHAR has white roots at nodes while POHY has black roots.

5. Cut all samples into ~3 inch or smaller lengths so they fit in paper lunch bags for the drying process and won't pierce the paper. Samples also need to be cut to this size, so they fit into the grinder after drying.

6. Place the samples in a 125-micrometer sieve and rinse gently in water to remove sediment. Don't use high water pressure that may pulverize soft detritus or other samples and push them through the wire mesh of the sieves.

   Samples that have a lot of sediment, such as some low marsh plots with small prostrate plants, may clog the sieve. Rather than increasing water pressure, which will tend to pulverize organic matter and push some of it through the mesh, it is preferable to use a 500-micrometer sieve for those samples.

Drying and weighing instructions

1. Dry samples in an oven for a minimum of 3 days at 60°C before removing. At the beginning of processing, test the dry time by removing 10 samples including 5 small and 5 large samples and weighing them after 2, 3, and 4 days or as long as necessary to achieve no net change in weight.

2. To weigh dry samples, pull about 20 samples out of the oven at a time and allow them to sit and cool off on the counter for about 15 minutes before weighing. When you start to weigh the first batch of samples, you can pull some more out of the oven to start cooling while you weigh the first batch.

   When you take samples out of the hot/dry oven, they will immediately start to absorb moisture (and weight) from the more humid/cooler room air, so it's important not to let them sit too long before getting the dry weight. If samples have been out of the oven for longer than 30 minutes they should be returned to the oven for additional drying before they are weighed.

3. Weigh and record weight of the sample and bag together first.

4. Then empty the contents of the bag out onto a large piece of heavy foil, being sure to get any dry biomass that might be stuck to the inside of the bag or might have collected under the seams/folds on the bottom of the bag. Weigh and record the weight of the empty dry bag so you can calculate the dry weight of the sample by itself.

5. If the sample is smaller than 1g in size use a higher resolution scale (4 decimal points) to record the weight. Some samples may be small enough that their dry weight registers as 0 on the coarse resolution scale because it falls within the range of error of the scale.

Separating leaves/stems

1. Separate the leaves/stems from live and dead samples after drying.

2. For C/N/Lignin analysis, we will ideally have about 10g of sample from which to extract a representative sample. This isn't always possible, but when we have large samples, we don't need to separate leaves/stems of the entire sample.

   For samples that are under about 30g, separate leaves and stems for the entire sample. For larger samples, just separate about 10-15g each of leaves and stems, and then leave the rest in its original paper bag as backup.

   Any flower or seed material should NOT be included with the leaves or stems. Flowers and seeds should be left in the leftover/backup bag.

3. Place the separated leaves and stems into two new bags labelled appropriately.

Grinding

For C/N/Lignin analysis the samples need to be ground. They don't need to be a fine powder but should be ground pretty small. We use as Waring commercial spice grinder WSG30 that runs at 19,000 RPM. Home coffee grinders may suffice as well, though they often overheat after a couple samples and shut off. They must sit and cool off before being used again. Note that some labs will grind samples, so this step may not be necessary.

Data Management and Analysis

This section provides a guideline, built upon our experiences in the Ecosystem Monitoring Program, on a structured and systematic approach for storing, preparing, and analyzing extensive biomass datasets.

Data Storage and Preparation: Efficient data analysis begins with organized data storage. For clarity and ease of access, we recommend storing the biomass dataset in a very-long format. This format facilitates seamless transitions between parameters using a toggle variable. It is advised that each data entry should come attached with time-stamps and relevant metadata, like sample location and time of year. Given the spatial characteristics inherent to biomass data, consider the use of spatial databases or GIS for enhanced data query and storage. Regular backups are a best practice to protect against any potential data losses. Once data is stored, the next pivotal step is its preparation. This involves diligent preprocessing activities to address any inconsistencies, aberrations, or missing data.

Analysis Considerations: When transitioning to the analysis phase, we recommend enriching biomass data by contrasting it against various ecosystem parameters. A practice of segregating the data, perhaps based on criteria like vegetation strata or species-specific contributions, can simplify the analytical process. An important avenue of exploration can be identifying correlations between biomass data and river discharge metrics, offering insights into the broader environmental influences on primary productivity.

A recommended focus in the analysis phase is integrating biomass data with other relevant datasets, like duration and frequency of flooding over the growing season, elevation of areas monitoring, and soil conditions. This holistic approach not only provides a deeper analytical perspective but can also shed

light on potential influencers or factors affecting biomass dynamics. Additionally, when using transect-based collection methodologies, it's crucial to be aware of potential challenges introduced by pseudo-replication. An understanding and due respect for the intrinsic structure of the data are crucial for sound conclusions.

By leveraging the years of data in the EMP aboveground biomass dataset, it becomes possible to conduct intricate analyses on nutrient development and export throughout the wetland. Such profound examinations shed light on estuarine dynamics and offer invaluable insights into the ecological health and functioning of the wetland ecosystem. Given the dataset's intricate nature, it's essential to harness advanced software tools and platforms like R, Python, or even specialized statistical packages. Such tools, complemented by platforms like Tableau or GIS software, aid in data visualization, enhancing data interpretation and the clarity of findings communicated.

Nutrient Content Analysis and Biomass Data Implications in Ecosystem Monitoring
The Ecosystem Monitoring Program (EMP) has demonstrated that the integration of nutrient content analysis with biomass data significantly enhances our understanding of wetland ecosystems. This augmentation provides valuable insights into nutrient dynamics, species decomposition rates, and overall contributions of different plant species to wetland ecosystems.

Key Findings and Benefits:

1. **Deepened Insights**: The examination of Carbon (C), Nitrogen (N), and ADF lignin (L) composition in the living above-ground biomass and detritus has elucidated the intricacies of nutrient dynamics across different plant species and between the high and low marsh strata.
2. **Decomposition Rates**: Analyzing species-specific functional plant traits, especially the C:N and L:N ratios, reveals the potential decomposition rates of species, offering insight into the ecological longevity and impact of different plant species within the ecosystem.
3. **Environmental Influence**: Patterns identified across elevation gradients, such as variations in plant species and their nutrient use efficiency, hint at broader environmental influences on primary productivity.
4. **Species-specific Data**: Notable findings, like the comparative analysis between the non-native grass *P. arundinacea* and the native sedge *C. lyngbyei*, provide critical information that aids in conservation planning and wetland management.

For researchers and conservationists, this combined approach of nutrient content analysis with biomass data offers a holistic view, allowing for more informed decisions, richer insights, and the development of effective conservation strategies. Embracing such a method, rooted in the experiences of the EMP, can significantly enhance ecosystem monitoring endeavors and contribute to the broader understanding of wetland dynamics.

References and Resources

The monitoring protocol can be found on monitoringmethods.org

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5.4 In-situ Measurements of Soil Conditions Using Extech Probes

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Background

Since 2017, the Lower Columbia Estuary Partnership has enhanced its habitat data collection by integrating in-situ soil measurements. Within both our Ecosystem Monitoring and Action Effectiveness Monitoring Programs, these soil evaluations now go hand-in-hand with vegetation, plant biomass, and sediment accretion data collection, offering a more comprehensive understanding of wetland dynamics.

Tidal actions and seasonal flooding conditions play a pivotal role in shaping soil conditions. Thus, in-situ measurements should be taken during uniform tidal and flooding stages, ideally at low tide, to maintain data comparability. While soil parameters dynamically change due to environmental factors and tidal and/or flooding durations, in-situ sampling aims to capture the general gradient among plant communities. Ensuring samples are collected under similar conditions and timeframes enhances their comparability. Additionally, to better understand wetland plant community dynamics, it's optimal to take these soil measurements during July/August vegetation surveys.

Using Extech brand probes designed for ORP, pH, Conductivity, Salinity, and Temperature, researchers can obtain real-time, direct measurements in the field. These metrics, when measured directly in wetlands, provide insights into the soil conditions that influence plant community dynamics:

ORP (Oxygen Reduction Potential): ORP directly assesses the electron transfer processes occurring in the soil. An elevated ORP often suggests oxygen-rich conditions, which might favor aerobic microbial activities and specific plant communities. Conversely, low ORP indicates anoxic or anaerobic conditions, which are common in saturated wetlands and support different plant and microbial communities. By measuring ORP in-situ, researchers can gauge the redox conditions of the soil, offering insights into microbial processes and potential plant species that can thrive in such conditions.

pH: Soil pH plays a pivotal role in determining nutrient availability. Many nutrients are more soluble and available to plants in specific pH ranges. Moreover, certain plant species are adapted to thrive in either alkaline or acidic soils. By measuring pH directly in the field, researchers can infer nutrient availability, microbial processes, and the potential plant community that the soil can support.

Conductivity: This metric gauges the soil's ability to conduct electrical current, which is directly influenced by the amount and type of dissolved salts in the soil. Higher conductivity usually indicates increased salt content, which can affect plant osmotic balance and overall growth. In-situ measurements help in understanding the salinity stress plants might face, guiding predictions about plant species composition.

Salinity: Directly linked to soil conductivity, salinity provides insights into the total dissolved salts present. In estuarine wetlands, where freshwater meets saltwater, salinity gradients can drastically influence plant zonation. Some plants are halophytes, specially adapted to high salinity conditions, while others may wither under salt stress. In-situ salinity measurements offer a direct window into this critical soil characteristic.

Temperature: Soil temperature can influence root growth, microbial activity, and biochemical processes. Certain plants are adapted to specific temperature ranges, with germination, growth, and reproduction being temperature sensitive. Direct field measurements ensure real-time capture of soil thermal conditions, helping in understanding the metabolic and growth potential of the resident plant community.

While in-situ measurements offer real-time data, sometimes, depending on research objectives and site conditions, soil samples may be collected and brought back to the lab for analysis. Lab-based evaluations provide controlled conditions for detailed measurements. However, this approach comes with its drawbacks: it's time-consuming and does not provide immediate insights into real-time soil conditions. Furthermore, potential alterations during sample transportation might skew the data. Thus, the research questions at hand should dictate which approach — in-situ and/or lab-based — is more suitable.

For the most meaningful analysis, it's essential that these soil measurements are co-located with other related data. Information on vegetation types, biomass, water depth, and other environmental factors, when collected simultaneously with soil metrics, can offer a more comprehensive perspective on wetland ecology, guiding restoration and management decisions.

Objective

Capture accurate, real-time soil characteristics in tidally restored wetlands using Extech probes. This data will help elucidate the soil determinants of plant community dynamics and inform wetland restoration and management efforts. Consistent timing (e.g., at low tide) and co-location with other environmental metrics ensure comparability and depth in the analyses.

Materials

- ORP probe (e.g., Extech TE300 ExStik ORP Meter)
- pH probe (e.g., Extech EC400 ExStik Waterproof Conductivity, TDS, Salinity, and Temperature Meter)
- Salinity probe (see above for example)
- Conductivity probe (see above for example)
- Temperature probe (see above for example)
- Digging tools
- Squirt bottle
- Calibration Solutions

Methods

We've published a presentation on this method update online, and it has helpful images. We recommend reviewing this in addition to reading the method details below. Presentation can be found here: Kidd et al. 2019. Revisiting Monitoring Protocols for Wetland Restoration. Science Work Group Presentation. Link

Field Measurements

In-situ measurements provide real-time data on soil conditions that dictate plant community dynamics in wetland habitats. Ensuring consistent and accurate measurements is pivotal for meaningful analysis.

Depth Significance:

The choice to insert probes 5 cm deep into the soil is not arbitrary. The 5 cm depth represents a critical zone where many biochemical activities that influence plant growth are most intense. This zone, often referred to as the rhizosphere, witnesses significant microbial activity and nutrient exchange, making it an optimal depth for capturing the immediate soil conditions that plants interact with.

For a comprehensive soil survey, within each quadrat (vegetation and/or biomass), in-situ soil measurements are taken using Extech soil probes placed at this depth. Measurements include salinity, conductivity, ORP, pH, and temperature. Always ensure these surveys are conducted in saturated soil conditions near peak low tide to ensure consistency and comparability. Moreover, systematically surveying in order of elevation, from highest to lowest, captures the gradient among various plant communities.

Data Collection Process:

1. Insert probes approximately 5 cm deep into the soil.
2. Wait for a few minutes for the probes to equilibrate with the surrounding environment, ensuring the recorded metrics are accurate.
3. Record each soil metric and its respective units, be sure to give the probe adequate time to settle into the reading.

Cleaning Probes:

It's crucial to clean probes after each measurement to prevent cross-contamination between sample locations. Contaminated probes can skew readings, rendering the data unreliable. Rinse thoroughly with distilled water or use specialized cleaning solutions if available. Ensure the tongs or tips of each probe are meticulously cleaned before progressing to the next plot.

Soil Compaction and Slurry Creation:

In areas where the soil is too compact, employing a fork can help in gently loosening it, making it conducive for probe insertion. If the soil remains too rigid, the creation of a slurry can facilitate measurements. However, it's essential that the consistency of the slurry remains as uniform as possible across all sampling locations to ensure data comparability. Pre-determine the soil-to-water ratio or method to achieve consistent slurry conditions across all sites. Always note on the datasheet, the method used (i.e., was a slurry used?) and the consistency of the soil and soil type/texture (clay, loam, silt, sand etc.). In some cases, the soil will be too dry for using soil probes in-situ, as this method is mainly intended to be used on fully saturated soil conditions, in these instances it will be important to note this and potentially consider taking soil samples for in-lab analysis.

When dealing with areas with standing water exceeding 10 cm in depth, manually hold the probe steady in the substrate to ensure consistent readings.

Always record soil metrics in conjunction with other monitoring activities such as vegetation grids, biomass plots, and sediment accretion pins to provide a comprehensive view of the ecological setting.

Calibration and Calibration Checks

Calibration is fundamental to ensuring the integrity and accuracy of data collected in the field. It's vital to understand the distinction between calibrating a probe and checking its calibration:

Calibrating a Probe: Calibration adjusts a probe to a known standard. For instance, calibrating a pH probe involves exposing it to a solution with a known pH value and adjusting it to read this value. Regular calibrations are essential as instruments can drift over time due to factors such as wear and tear.

Checking the Calibration: This is a verification step, testing the probe in a known solution to see if it reads correctly without making adjustments. If the probe reads correctly during a check, full recalibration may not be necessary. However, discrepancies signal the need for recalibration.

Before and after each field session, it's crucial to conduct and record a calibration check on all probes to ensure measurements are consistent and reliable. If a probe's readings display an error margin greater than 10% for any metric during these checks, it signals the need for a full recalibration to maintain data integrity.

Even with regular calibration checks, establish a routine schedule for complete calibrations. Maintain detailed logs, recording the date, time, results, and any subsequent actions taken.

For detailed calibration instructions, particularly for ORP and pH/Conductivity probes, always refer to the respective model's manual, ensuring that the calibration process is executed with precision and accuracy.

Data Management and Analysis

There are numerous analyses one can conduct with soil information; however, one use is for drawing trends and expectations about expected plant development at specific elevations.

Data Management and Analysis

Managing and analyzing soil data is crucial for drawing out meaningful interpretations about wetland ecosystems. To achieve this, we recommend a structured approach for storing and processing the data.

Database Management:

For clarity and to maintain data integrity, all soil condition metrics measured in the field should be compiled into a centralized database. This approach ensures that all relevant data is easily accessible, organized, and ready for analysis. The database structure should be designed to facilitate cross-referencing with other related datasets, thus enabling comprehensive analyses.

Below is a suggested format that our team has found effective for data storage (Table 10):

Table 10: The format for the soil data warehouse. Note that Transect and Plot are used to relate the soil data to other databases. The Type field refers to the type of plot (namely, either vegetation plot, biomass plot, or sediment accretion stake).

Site Name	Transect	Plot	Date	Year	Time	Type	Dominate Veg Type	Water Depth (cm)	pH	SAL (ppm)	CON (µS)	ORP	Temp (C˚)	Soil Texture	Notes	Surveyor

Note: In this format, the 'Transect' and 'Plot' fields serve to correlate the soil data with other related datasets. The 'Type' field categorizes the type of data plot (either vegetation, biomass, or sediment accretion stake). This categorization aids in streamlined data retrieval and analysis.

Analysis Considerations:
With a well-organized soil data repository, various analytical approaches can be undertaken. One fundamental use of this data is to identify trends and develop projections regarding plant community dynamics at specific elevations. By understanding the interplay between soil conditions and plant growth, researchers can gain insights into the factors that influence plant species distribution and abundance in tidal wetland habitats. For instance, examining the relationship between parameters like pH, ORP, and salinity against dominant vegetation types can shed light on plant community preferences for certain soil conditions.

Establishing a time-series database becomes particularly valuable for long-term wetland monitoring, especially after restoration efforts. Such a database allows researchers to track changes and shifts in the wetland over time, offering a dynamic view of the restoration's impact on soil properties and, consequently, on plant community structures. As restoration projects evolve, this time-series approach can highlight success points, areas needing further intervention, or unexpected changes that may arise. Furthermore, the data, when used in conjunction with other ecosystem parameters like dominant species abundance, plant biomass, water depth, and duration of flooding over the growing season, can provide a multifaceted view of wetland health, dynamics, and the factors driving them. As soil conditions are often a reflection of broader environmental changes, continuous monitoring and analysis can also help in the early identification of any ecosystem disturbances.

When analyzing this data, remember that in-situ measurements provide a snapshot of real-time conditions. Comparability is key; thus, ensure that data collected across different sites adhere to the same protocols and conditions, such as time of day or tidal conditions.

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5.5 Collecting Soil Cores for Lab Analysis

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Background

The Lower Columbia Estuary Partnership's Ecosystem Monitoring Program (EMP) emphasizes the importance of understanding soil dynamics, particularly within wetland habitats. As part of this, the program has adopted the practice of monitoring soil conditions using extracted soil cores. This methodological choice is not only pivotal for assessing reference site conditions, such as those at EMP sites, but it's also essential for comprehensively evaluating restoration sites. Monitoring soil conditions both pre- and post-restoration interventions helps decode the intricate processes driving the recovery and development of hydric soil conditions. Such in-depth understanding becomes even more critical in light of potential ecological shifts prompted by actions like breaching levees, grazing removal, and broader challenges posed by climate change. The invaluable insights from these practices owe much to the foundational contributions of Roger Fuller and Katrina Poppe in 2017-2018.

Objective

Extracting and analyzing soil cores offers a comprehensive perspective on wetland soil health and its dynamics, vital for both the design and evaluation of restoration actions and ecological status and trends. Each of the key soil parameters provide specific insights:

- **Bulk Density:** This metric, indicating soil compactness, sheds light on its aeration and root permeability. Optimal bulk densities in wetland ecosystems facilitate efficient gas exchange crucial for the health of both plants and microbial communities. Fluctuations in this metric can pinpoint compaction problems, which might affect both water movement and root growth.
- **Organic Matter Content:** Representing the amount of decaying organic material, this parameter acts as a gauge for soil fertility and its capacity for moisture retention. Elevated levels typically signify a vibrant wetland, characterized by active decomposition and nutrient cycling.
- **Soil Texture:** The blend of sand, silt, and clay in the soil determines its drainage capabilities, aeration, and moisture holding capacity. These characteristics shape the type of plant communities that can thrive within.
- **Nutrient Content:** Elements like carbon and nitrogen provide insights into the soil's nutrient profile, influencing its capability to nurture varied plant life. For wetlands, achieving the right nutrient equilibrium is key, as imbalances might promote the dominance of specific plant species, potentially reducing biodiversity.
- **Soil Moisture Content:** A direct measure of the wetland's prevailing hydrological conditions, soil moisture content impacts plant growth, microbial activities, and biochemical processes in the soil. Consistent monitoring of this metric can help detect and understand shifts in wetland conditions due to factors like climate change or conservation interventions.

For conservation endeavors in wetland ecosystems, ongoing soil monitoring across both restoration and reference sites is paramount. It highlights the progression and effectiveness of restoration activities, forming the foundation for future conservation strategies. These methods serve as a perfect complement to the in-situ soil data collection highlighted in section 5.4: ORP, pH, Conductivity, Salinity, and Temperature. Moreover, co-locating these soil parameters with in-situ measurements and the

vegetation or biomass data collection, as discussed in previous sections, enables a robust, holistic analysis of wetland habitats.

Materials

- 2-inch PVC coring tubes with sharpened end (for a depth of 10 cm)
- Spade
- Sharp knife
- Mallet
- Cooler with ice
- Gallon-sized Ziploc plastic bags
- Drying oven
- Precision balance for weighing
- Ceramic or metal pans for drying

Methods

Field Collection

1. Identify the precise sampling location. It's crucial to ensure a representative spread across the wetland area.
2. Utilizing the 2-inch PVC coring tube, marked for a depth of 10 cm, penetrate the soil to the designated mark. This coring tube captures a volume of approximately 201.06 cm3, making subsequent bulk density calculations straightforward.
3. For more compact soils or those with a harder surface, the mallet may be required to drive the PVC core tube into the ground.
4. Once the core is collected, use the spade and knife to isolate the core, ensuring it remains intact.
5. In instances where the core seems highly organic, implying less soil mass, it might be essential to extract supplementary soil from the same location to guarantee adequate weight for precise lab analyses. Note: Keep these samples distinct until the primary sample's bulk density gets determined.
6. Deposit the soil sample into a plastic bag, removing as much air as possible before sealing. Store it in the cooler to maintain its integrity during transportation back to the lab.

Lab Analysis

1. Weighing and Drying: On arrival in the lab, weigh the wet soil sample using the precision balance and record the weight. This is the 'wet weight'.
2. Transfer the soil to a ceramic or metal pan, spreading it out evenly.
3. Place the pan with the sample into the drying oven set at 105°C. Allow the sample to dry for 48 hours to ensure all moisture is eliminated.
4. After the drying period, reweigh the soil sample. This is the 'dry weight'. The difference between the wet and dry weights provides the soil moisture content.
5. Bulk Density Calculation: Using the volume of the coring tube (201.06 cm3) and the dry weight of the soil, calculate the bulk density with the formula:
6. Bulk Density (g/cm^3) = Dry Weight (g)/ Volume (cm^3)
7. Further Analyses: Depending on the specific research questions, you can now proceed with analyzing the soil for various parameters. Here's a breakdown of potential analyses and recommended methodologies:

- Organic Matter Content (Loss on Ignition): The content of organic matter in the soil can be determined through the loss on ignition method. For a detailed procedure, refer to the methods described by Kalra and Maynard (1991).
- Nutrient Levels (Nitrogen and Phosphorous): To assess the concentration of nitrogen and phosphorous in the soil samples, employ the Kjeldahl digestion technique. This method is well-documented by Bremmer (1995) and Taylor (2000).
- Soil Texture: A vital parameter, the soil texture (proportion of sand, silt, and clay) influences various soil properties. For guidance on analyzing soil texture, consult the protocols outlined by Kalra and Maynard (1991).
- Dried Soil pH, Cation Exchange Capacity (CEC), and Sodium (Na) Content (% CEC): To determine these crucial parameters, follow the standardized methods provided by Gavlak et al. (1994).
-

By following these established methodologies, you ensure the accuracy and reliability of your soil analyses, providing valuable insights into the health and dynamics of the wetland ecosystem. Further references and resources are provided at the end of this section to provide guidance on these options.

Data Management and Analysis

Effective management of lab-analyzed soil data is pivotal for deriving robust and insightful conclusions about wetland soil health and its impact on ecosystems. All lab-analyzed soil data should be consolidated into a centralized database, ensuring the information remains organized, accessible, and primed for nuanced analysis. Within this database, each entry might include fields for the site name, transect, plot, date, year, time, sample type, sample depth, bulk density, organic matter content, soil texture, soil moisture, nutrient content, and associated notes. Importantly, the 'Transect' and 'Plot' fields connect the lab-analyzed soil data with other relevant datasets, while the 'Type' field delineates the purpose or origin of the sample, aiding in rapid data retrieval and contextual understanding.

In terms of analysis, several approaches stand out. One can assess how soil parameters, such as organic matter content, texture, and nutrient levels, vary with location elevation, dominant plant communities, types of restoration approaches etc. This analysis offers insights into the variability of nutrients and organic matter, potentially guiding interpretations of plant community patterns and microbial activity. Comparative analysis is another avenue, where lab-analyzed data can be juxtaposed with in-situ measurements. For instance, associating bulk density with in-situ measurements like ORP or salinity can illuminate the interconnectedness of soil structure with specific chemical attributes.

Moreover, the emphasis on time-series monitoring becomes especially pertinent for restoration projects. By systematically tracking changes in soil properties over time, researchers can discern the ongoing effects and efficacy of restoration activities, fostering informed decisions and adaptive management strategies. Integrating lab-analyzed data with additional ecosystem parameters, such as dominant vegetation types, plant biomass, water depth, and flood duration, provides a comprehensive perspective on wetland health, its evolutionary dynamics, and the key influencing factors. Lastly, a vigilant approach to data analysis can be instrumental in detecting potential ecosystem disturbances, as alterations in soil properties can often be precursors to more widespread environmental shifts.

Consistency in data collection and analysis protocols is a foundational requisite. Soil cores extracted from different sites or at diverse times should adhere to uniform methodologies to ensure comparability, thus bolstering the reliability of trend analyses and derived insights.

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6. Macroinvertebrates

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Background

All macroinvertebrate sections below are authored by Toft et al. listed above unless otherwise noted. Within the Ecosystem Monitoring Program (EMP) and the Action Effectiveness Monitoring and Research Programs (AEMR), the monitoring of macroinvertebrates unveils a suite of vital methodologies, including Benthic Cores, Fall-out Traps, Neuston Nets, and the examination of fish stomach contents (detailed in Chapter 7). These techniques serve as linchpins in comprehending the intricate ecosystem dynamics of the Lower Columbia River Estuary.

Macroinvertebrates, as fundamental components of aquatic food webs, often play the role of primary prey for juvenile salmonids. Their ecological significance cannot be understated. This section immerses us in the world of macroinvertebrate sampling, shedding light on their distribution, abundance, and community structure. Moreover, it offers insight into the trophic relationships and growth dynamics of these organisms by considering zooplankton quantities, a crucial aspect of estuarine ecology.

Decisions regarding the choice of sampling methods, such as Benthic Cores, Fall-out Traps, or Neuston Nets, are often influenced by research objectives and cost considerations. The transition from one method to another entails trade-offs depending on the specific research questions and goals. In this chapter, we explore these methodological choices and their implications, providing a comprehensive view of macroinvertebrate sampling in the Lower Columbia River Estuary.

6.1 Sampling Macroinvertebrates using Benthic Cores

Background

In the context of the Ecosystem Monitoring Program (EMP) and the Action Effectiveness Monitoring and Research Program (AEMR), Benthic Cores serve a dual purpose. They play a vital role in understanding the complex world of benthic macroinvertebrate assemblages, aiding in the characterization of their presence and diversity. Simultaneously, these cores provide critical insights into the availability of benthic prey resources for juvenile salmonids, which are fundamental during their early life stages. This method, tightly integrated with broader research objectives, is pivotal for assessing ecological changes within tidal wetlands and deciphering trends in prey availability. This is particularly pertinent for ESA-listed juvenile salmon, both before and after habitat restoration efforts.

Objective

The objective of this protocol is to characterize benthic macroinvertebrate communities and evaluate the availability of benthic prey resources for juvenile salmonids. By comparing macroinvertebrate communities and abundance, we gain valuable information about the changes occurring at the macroinvertebrate trophic level in tidal wetlands. Benthic cores are a versatile tool that can be combined with fall-out traps and gastric lavage

samples to create a comprehensive picture of prey availability trends, including the diet preferences of ESA-listed juvenile salmon.

Materials

- Three-inch diameter PVC pipe
- Sieve with a 500 µm mesh
- Rubber stopper that fits snugly into the PVC pipe
- Jars (16 oz) with lids
- Labels on write-in-the-rain paper
- Pencil
- Sharpie marker
- 70% denatured ethanol/rose-bengal solution
- Electrical tape
- Ruler
- Duct tape

Methods

1. **Sampling Locations**: Benthic cores should be sampled at locations directly adjacent to those where the fish community, food web metrics, and vegetation are being sampled. These cores are typically collected monthly during juvenile salmon outmigration.
2. **Sampling Conditions**: Sampling should occur during low tide when sediments and emerged vegetation are exposed. This allows us to sample areas regularly inundated by tidal waters. Sample sites should be chosen below the high tide line near the bottom of the channel.
3. **Core Collection**: The number of cores to be collected will vary depending on the specific study. In general, aim to collect three to five cores during each sampling event.
4. **Sample Consistency**: To ensure a consistent sample size, measure 10 cm from the bottom of a 3-inch diameter PVC pipe and mark it with duct tape. Insert the core up to the duct tape, cap the core to create suction, and gently remove the core from the substrate. This method works best with fine sediment samples.
5. **Sample Preservation**: Empty the contents of the core into a properly labeled plastic sample jar. Ensure that the label includes the date, time, site, sample number/ID, and the initials of the sampler.
6. **Processing at the Lab**: Back at the laboratory, sieve and process each sample. Rinse the sediment out of the container into the sieve under a water nozzle. After rinsing the sediment from the sample, rinse the jar and any lid remnants into the sieve as well.
7. **Sample Transfer**: Transfer the sample from the sieve back to the jar using a squeeze bottle of water. Add 100% formaldehyde to the jar contents to create a 10% formalin solution (i.e., 90% water and sediment). Lightly stir the contents to ensure that the solution reaches all parts of the jar.
8. **Labeling and Storage**: Fill out the label with a pencil and place it into the jar. Close the jar with its lid, and use a Sharpie marker to label the lid with the same information as on the paper label. Seal the lid onto the jar with electrical tape. Store the samples in a container that is tightly closed and sealed.

Data Management and Analysis

In the laboratory, identify the benthic core invertebrates using high-resolution optical microscopy and taxonomic references (Mason 1993, Carlton 2007, Merritt et al. 2019, Thorp and Covich 2014, Triplehorn and Johnson 2005). For each sample, count the number of individuals in each taxonomic

group, blot each group on tissue, and weigh them to the nearest 0.0001 g. Identify individuals to the class, order, family, and, when possible, to the species level. Taxa that are not aquatic or benthic in their ecology, such as adult flies, may be excluded from benthic core data analyses.

For high-density samples, consider subsampling via volumetric subsampling. Dilute the sample to a specific volume that adequately represents the assemblage and contains over 100 total organisms. Process a portion of this volume and calculate total counts as a ratio of the volume sampled.

Calculate numeric composition (count proportion) and gravimetric composition (weight proportion) for invertebrate taxa. The numeric composition, or density, of a taxon, is calculated as the total count for a given taxon divided by the core volume (number of individuals per cubic meter). The gravimetric composition, or biomass, of a taxon, is calculated as the total weight of the taxon divided by the core volume (weight of individuals per cubic meter). To compare taxa densities and biomass between study sites, sum density and biomass data for each taxon across replicate samples within a given site for a given period and divide by the number of replicates. The result is an average total density and biomass at each sampling site per period.

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Benthic core sampling protocols can also be found at monitoringmethods.org (Method ID 1593).

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6.2 Sampling Macroinvertebrates using Fall out traps

Background

Tidal wetland restoration work in the Columbia River Basin is centered around the enhancement of salmonid habitats, especially those critical for juvenile salmon. Shallow off-channel habitats are believed to provide essential refuge and foraging opportunities for these young fish during their first year in freshwater environments. Much of the restoration effort focuses on increasing native plant cover. The use of fall-out traps in patches of varying vegetation, both native and invasive, as well as at reference or control sites, allows for the investigation of relationships between macroinvertebrate species diversity and abundance and plant community composition, providing valuable insights into the success of restoration efforts.

Objective

Methods for fall-out traps are adapted from the United States Geological Surveys' Terrestrial Invertebrates Standard Operating Procedures (2012). The primary objective is to assess the macroinvertebrate communities in tidal wetlands, particularly in areas targeted for restoration, and understand how they relate to the vegetation composition. This method aids in evaluating the effectiveness of restoration actions, especially with regard to providing suitable habitats for juvenile salmonids.

Materials

- ¾ inch PVC
- Mallet
- Rectangular bins
- Drill
- String
- Garden sprayer
- Filtered water
- Biodegradable unscented liquid dish soap
- Sieve (106 or 350 μm mesh)
- Specimen jars with lids
- Denatured Ethanol or Isopropanol
- Electrical Tape
- Write in the rain label
- Pencil

Figure 22. Examples of fall out traps.

Methods

The location and number of fall-out traps selected for a site will depend largely on the specific project goals, site conditions, access, and funding. Factors including site complexity, microtopography, and vegetation assemblage(s) should be considered when selecting the location of fall-out traps. Traps should be placed near channels and designed to rise and fall with the tide. Placing all traps on one side of the channel can reduce trampling wetland vegetation and simplify access. For habitat comparison, traps should be paired in areas of native vegetation *(Carex obnupta, Eleocharis spp*.) and in areas of invasive species *(Phalaris arundinacea*).

When selecting the mesh size for your sieve (106 or 350 μm), consider the specific objectives of your study. A 106μm mesh will capture a broader range of macroinvertebrates, including smaller organisms, which can provide a more comprehensive view of the community. However, a 350μm mesh may be preferred if you are targeting larger macroinvertebrates or if your study focuses on specific taxa. Your choice should align with the goals of your research and the ecological questions you seek to answer. Additionally, the mesh size should be consistent across all traps within a study to ensure data comparability.

Drill holes on all four sides of the tub that are large enough to thread string through. Three to four PVC poles are used per fall-out trap. They are spaced around the plastic bin used for sampling; bins should be the same size for all traps. Tie string through each hole in a loop long enough to go around each PVC pole; the string needs to be able to slide up/down the pole with changing water levels. Since traps rise with the tide and settle back to the ground on their own, they require a mostly level base to prevent contents from spilling if traps rest ajar on the ground. Cut-off tomato cages, PVC with elbows, or any other base can be used to keep the trap from landing diagonally on uneven ground and spilling.

To deploy

Locations should be selected at low tide to evaluate substrate and vegetation; however, fall-out traps can be deployed and collected during high tide if boating makes for easier access.

Place the bin on the ground and pound three to four PVC poles into the ground around the bin, making sure the poles are not touched up against the bin so it can move freely with the tides. Be sure the bin is clean and free of any invertebrates or plant debris that may pollute the sample.

Loop the string around the poles and let rest on the ground or water surface. Add a dime-sized dollop of biodegradable soap to the bin to break water surface tension; too much soap will clog the sieve during collection. Water filtered through a 106 micron or finer sieve can be carried in or water from the adjacent stream filtered into the bin. Not filtering water can result in aquatic species such as Sminthuridea flooding the sample and not being representative of terrestrial macroinvertebrates present onsite.

Pour several inches of filtered water into the bin. The amount of water should be adjusted to account for rainfall or evaporation over the deployment duration. Traps should be deployed for 24-48 hours or as close as possible; macroinvertebrates may begin decomposing after this period making identification difficult. Record the date and time of deployment.

To collect

When collecting traps make note of any damage or spillage. Slowly pour the sample through a 350 □m mesh sieve; this can be done over a clean bin to prevent losing any of the sample during sieving. Use a garden sprayer with filtered water to rinse the tub through the sieve and to rinse extra soap out of the sieve. Aggressive rinsing can damage macroinvertebrates, separating wings or legs that are critical for identification. To minimize damage to the sample contents, gently rinse the sample from the sieve into the sample jar, minimizing the amount of water in the jar. An excess of water may risk proper preservation of the contents and the sample will not be usable. Proper sample preservation requires concentrations of 70% alcohol (ethanol or isopropanol) and 30% water. Tweezers may be used, but they

will need to be rinsed into the jar so none of the sample is lost and may damage invertebrates in the sample.

Fill out a label with pencil that includes date, time, site, sample ID, and sampler. Additional labeling can be done with a sharpie on the jar and or lid. Be sure that there is a label in the sample as writing on the outside of the container can come off, wrap electrical tape around the lid several times to prevent evaporation or spilling of contents.

Data Management and Analysis

In the laboratory, the analysis of fall-out trap samples involves a series of steps to derive meaningful insights into the macroinvertebrate community and its ecological significance. High-resolution optical microscopy and taxonomic references (Mason 1993, Merritt et al. 2019, Thorp and Covich 2014, Triplehorn and Johnson 2005) are indispensable tools for accurate identification. Here is a step-by-step breakdown of the analysis process:

1. **Sample Preparation:** Begin by separating the collected organisms from the preservative solution using the appropriate mesh size (either 106 or 350μm) sieve, as determined during sample collection. The choice of mesh size should align with your research goals, as discussed earlier. Carefully rinse the organisms to remove any residual preservative.
2. **Counting Individuals:** Once separated, count the number of individuals within each taxonomic group. This step is crucial for understanding population dynamics and assessing the relative abundance of different species or taxa.
3. **Tissue Blotting:** After counting, blot each taxonomic group on tissue paper. Blotting helps remove excess moisture while preserving the integrity of individual specimens, making them suitable for further taxonomic identification.
4. **Weighing:** Weigh each taxonomic group to the nearest 0.0001 gram using a precise scale. This step provides data on the biomass of each group, which is valuable for assessing the ecological role of different taxa in the food web.
5. **Taxonomic Identification:** Identify individual organisms to the desired taxonomic level. Typically, taxa that are crucial to the diet of juvenile salmon, such as Chironomidae, are identified to the family level for more detailed analysis. Other taxa may be identified to higher taxonomic levels (e.g., order) if they are not the primary focus of your study. Taxonomic references, as mentioned earlier, should guide this process.
6. **Data Organization:** Maintain a meticulous record of all collected data, including date, time, site, sample ID, and sampler information. This ensures that your findings are well-documented and reproducible.
7. **Data Analysis:** Once taxa have been identified and quantified, you can proceed with data analysis. Depending on your research goals, you can calculate various ecological metrics, such as species richness, diversity indices, and community composition. Statistical analyses can help you detect patterns, relationships, and ecological changes in the macroinvertebrate community across different sites or over time.
8. **Interpretation:** Finally, interpret your findings in the context of your research objectives. Consider how the composition and abundance of macroinvertebrate taxa may influence the overall health of the ecosystem and, in particular, their significance as prey for juvenile salmonids.

By following these systematic procedures and recording your results diligently, you'll contribute valuable insights to the understanding of tidal wetland ecosystems and their importance for salmonid habitats. These insights can inform conservation and restoration efforts.

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6.3 Neuston Net for Sampling Macroinvertebrates

Background

Within the scope of the Ecosystem Monitoring Program (EMP) and the Action Effectiveness Monitoring and Research Program (AEMR), Neuston Net sampling fulfills a dual role. It assumes a crucial role in unraveling the intricate realm of surface-dwelling macroinvertebrate communities, aiding in their identification and quantification, all while shedding light on their abundance and diversity. Simultaneously, these samples offer invaluable insights into the presence of surface-dwelling prey resources for juvenile salmonids, which hold utmost importance during their early developmental phases. This method, seamlessly integrated into our overarching research objectives, holds immense significance in evaluating ecological shifts within tidal wetlands and elucidating patterns in prey availability. This holds relevance for ESA-listed juvenile salmon, both in the periods preceding and following habitat restoration initiatives.

Objective

The objective of the EMP and AEMR Neuston sampling efforts is to quantify macroinvertebrate taxa, which serve as potential prey for juvenile salmon, within tidal channels and nearshore areas. This comprehensive sampling approach involves the collection of Neuston samples at both long-term reference sites, monitored monthly from March to September, and restoration sites surveyed annually during peak salmonid migration. These parallel approaches provide invaluable insights into the overall conditions of the estuary as well as the specific conditions of restoration projects over time.

Time-series measurements are meticulously recorded to evaluate differences between months and years, ensuring a thorough understanding of temporal variations. Taxa encompass a wide spectrum, including planktonic organisms (e.g., copepods and cladocerans), entrained benthic species (e.g., amphipods, ostracods, oligochaetes, and nematodes), the aquatic phase of terrestrial insects (e.g., chironomids), and the fall-out of terrestrial invertebrates (mainly insects and arachnids). Notably, Neuston macroinvertebrate samples are consistently paired with concurrently sampled Chinook salmon stomach contents (Chapter 7). This meticulous data collection approach facilitates the development of a comprehensive dataset that can inform restoration management strategies, track ecosystem recovery progress, and provide a broader understanding of estuary-wide trends.

Materials

The neuston net consists of a 69 cm (27-inch) long, 250-micron mesh net set in a 20 x 40 cm (8 x 16-inch) PVC frame. The net opening of 800 cm^2 (128 in^2) tapers to an 8.9 cm (3.5-inch) outside diameter, 10 cm (4-inch) long PVC collar connected to the net with a rubber-coated hose clamp. A codend cup, 8.9 cm outside diameter x 15 cm long (3.5-inch outside diameter x 6 inches long) with a bottom filtering section, joins the collar with quick-release latches. The net bridle consists of a small-diameter rope with attachment points from each corner that meet in the center approximately 46 cm (18 inches) in front of the frame, where the tow line attaches.
Additional equipment and materials required include:

- Jars with lids
- Waterproof labels
- #250-micron sieve, 20 cm (8-inch diameter)
- 95% ethanol

- Forceps and/or spoon
- Garden sprayer
- Boat pole
- Cooler or insulated container (for sample transportation)
- GPS unit (for recording location data)
- Notebook or datasheet (for recording field notes)
- Waterproof pen or pencil (for writing on labels and datasheets)
- Camera (for documenting sampling sites)
- Water quality measurement instruments (e.g., thermometer, conductivity meter, etc.)

Methods

For the EMP and AEMR programs, neuston samples are collected at both reference sites and restoration sites. For AEMR sites two habitat types at each site are sampled for macroinvertebrates: emergent vegetation (EV) along the vegetated wetland marsh margin adjacent to open water, and open water (OW) in the center of the marsh channel. Two samples are collected in each habitat type per site visit. During periods of low water when no vegetated edge is available, only the open water samples are collected.

Emergent marsh samples are collected by walking the Neuston net for 10 meters through the vegetation, suspending it from the tip of the boat pole using the tow rope. Care is taken to direct the net through undisturbed areas (in front of or to the side of the person collecting the sample). The water depth should be at least 25 cm deep to ensure that the top 20 cm of the water is sampled, avoiding contact with the benthos. For the OW sample, the net is suspended from a boat pole off the bow of a boat and pushed at idle speed for 100 meters through undisturbed water, holding it so that the top 20 cm of the water column is sampled.

For EMP sites, neuston samples are collected in OW at the same location of fishing in the site's main channel (see Chapter 7).

A garden sprayer is used to wash samples into the net codend. Water for the sprayer should be filtered through the #250-micron sieve. Once a tow is completed, rinse the net from the outside, guiding the interior contents into the codend, and empty the contents into an appropriately sized jar. Adjust the water content so the sample is preserved in a 70% ethanol solution. Each jar should have an interior waterproof label written in pencil that includes, at a minimum, the site name, date, habitat type, and replicate number.

Data Management and Analysis

Invertebrates collected in Neuston tows are identified in the lab using high-resolution optical microscopy and taxonomic references (Mason 1993, Kozloff 1996, Merritt and Cummins 1996, Thorp and Covich 2001, Triplehorn and Johnson 2005). Most individuals are identified to the family level, although some groups or individuals are identified to coarser levels (e.g., order). For each sample, the

number of individuals in each taxonomic group is counted, and each group is blotted dry and weighed to the nearest 0.0001 g.

Descriptive statistical analysis of the entire invertebrate community is calculated, in addition to specific analyses of the order Diptera (flies) and amphipod taxa, which have been shown to be important prey for juvenile Chinook salmon in the lower Columbia River (Lott 2004, Spilseth and Simenstad 2011). For Neuston tows, the density and biomass of taxa in each sample are calculated as the total count or weight for a given taxon divided by the meters towed (# individuals m-1 towed, mg m-1 towed). Alternatively, concentrations (ind/m3) can be estimated from net mouth area × distance swept. To compare taxa densities and biomass between study sites, density and biomass data for each taxon are summed across replicate samples taken within a given site each month and then divided by the number of replicates to give an average total density and biomass at each sampling site per month.

Multivariate analyses are used to examine differences in the invertebrate assemblage between sites (Clarke and Warwick 1994, Clarke and Gorley 2006). Taxa are initially combined into taxonomic groups for analysis of community composition. Similarity indices are calculated for the average site abundance of each invertebrate taxon using the Bray-Curtis similarity coefficient as a measure of the distance between sites. The density data are log-transformed prior to analysis. A non-metric, multi-dimensional scaling (MDS) ordination plot is used to show similarity. The MDS plots observations as points, where those close together represent samples similar in community composition, and points far apart correspond to different composition values.

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The monitoring protocol can be found on monitoringmethods.org (Method ID)

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6.4 Sampling Zooplankton

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Background

Within the framework of the Ecosystem Monitoring Program (EMP), our investigations extend to the realm of zooplankton. Zooplankton are aquatic organisms, typically ranging in size from approximately 50 µm to over 250 µm, playing a fundamental role as secondary producers at the base of the aquatic food web. Our primary focus lies at our five long-term EMP monitoring sites, where we aim to comprehensively assess zooplankton densities and composition. To achieve this, we employ a methodology involving duplicate net tows conducted in open water. This approach helps us gain insight into both the abundance and diversity of zooplankton and the presence of surface-dwelling prey resources, which are of paramount importance for the early developmental phases of juvenile salmonids.

Furthermore, this zooplankton sampling method is a valuable tool for researching the impacts of habitat restoration on salmonid habitat. By consistently employing this method before and after restoration initiatives, we can track changes in zooplankton abundance and composition, providing critical data for assessing the restoration's effects on the availability of essential prey resources. These insights enhance our understanding of how habitat restoration efforts influence the broader ecological dynamics of the tidal wetlands and support the conservation of ESA-listed juvenile salmon.

Objective

Understanding secondary production in aquatic ecosystems is crucial as it links organisms at higher trophic levels to primary producers, fundamentally contributing to ecosystem function (Dolbeth et al. 2012). Secondary productivity, which represents the rate of growth of consumers of primary production, can be challenging to measure directly but can be estimated using various methods, including the assessment of growth rate, enzyme function, and population dynamics (Setubal et al. 2020). In our work, we record the composition of zooplankton assemblages and determine their densities during the spring and summer seasons, providing a coarse estimate of secondary production.

Diet analysis has highlighted the significance of copepods and cladocerans as major components of the diet of juvenile salmonids in the low Columbia River wetlands when these zooplankton are present in high densities in the environment (Kidd et al. 2022). Additionally, there has been a growing recognition of the importance of smaller zooplankton species, including rotifers and ciliates, in secondary production within aquatic systems (Dias et al. 2014). Hence, our data collection encompasses a wide range of zooplankton species, including rotifers, ciliates, crustacean zooplankters (e.g., copepods, cladocerans), annelids, nematodes, and invertebrate larvae.

Sampling Methodology

- **Sample Collection**: Zooplankton samples are collected during trips for maintaining water quality sondes and analyzing nutrients, chlorophyll, and phytoplankton.

- **Use of Plankton Net**: Zooplankton often exist at relatively low densities, making whole water samples inefficient for processing and analysis. To overcome this, we employ a plankton net with an 80 µm mesh size, 0.5 m diameter, and 2 m length.
- **Tow Procedure**: The net is submerged just below the water surface (usually less than 1 m depth) and either pulled through the water by hand or dragged from a small boat for 3-5 minutes or approximately 100 m.
- **Flow Meter**: To determine the volume of water that the concentrated zooplankton occupy, a flow meter (e.g., General Oceanics Inc., Model 2030R) is used.
- **Sample Preservation**: The concentrated zooplankton material is collected into the cod end of the net and transferred into 500 mL glass jars. To sedate the zooplankton, approximately 20 mL of soda water is added, and they are preserved using formalin (37% formaldehyde) for a final concentration of 2-4%. These net tows are performed in duplicate. Microzooplankton, including ciliates and rotifers, are preserved in whole water samples using Lugol's Iodine (1% final concentration; James, 1991).

Laboratory Analysis

Equations:

- The distance covered (in meters) is determined from:

$$Distance = \frac{Difference\ in\ counts\ \times\ Rotor\ Constant}{999999}$$

  where the difference in counts refers to the difference between the initial and final counts on the six-digit counter, which registers each revolution of the instrument rotor.

- The speed is calculated from:

$$Speed = \frac{Distance\ in\ meters\ \times\ 100}{Time\ in\ seconds}$$

- The volume is determined as:

$$Volume\ in\ m^3 = \frac{3.14\ \times\ net\ diameter^2\ \times\ Distance}{4}$$

- **Calculations:** Upon returning to the laboratory, calculations are made to determine the total volume of water that passed through the plankton net, allowing us to calculate the density of zooplankton in the water**.**
- **Sample Splitting:** The concentration samples are split using a Folsom plankton splitter, enabling examination of a reasonable volume of material under the dissecting microscope for larger zooplankton such as copepods and cladocerans or under the inverted microscope for microzooplankton.
- **Enumeration and Identification:** The individuals are identified and enumerated during examination in a plankton wheel or plankton counting chamber, typically including 10-20 mL of sample.

Data Management and Analysis

Data are collected on physical count sheets, which are transcribed to Excel spreadsheets and stored on a secure cloud-based server. The counts are converted to cell density, or concentration, using information about the volume captured in the tow as well as the volume of the original sample examined in the microscope. The specimens enumerated are broadly categorized into taxonomic groups that include: rotifers, cladocerans, annelids, ciliates, and copepods, and 'other.' Within these groups, we identify the individuals to a genus or species where possible (rotifers, cladocerans, ciliates, annelids), or to order (copepods).

References

The monitoring protocol can be found on monitoringmethods.org (Method ID)

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7. Fish

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Background

These methods, applicable across a range of ecosystem monitoring and research initiatives, have been written and reviewed by NOAA, a key partner in data collection and analysis. While NOAA's contributions are particularly evident in the context of the CEERP Ecosystem Monitoring Program and the Action Effectiveness and Research Program, the methodologies outlined here are designed to be relevant to a wider array of environmental studies. Regarding the fish monitoring chapter (7) of this document, it is important to note that there is a consolidated reference section (7.8), and individual subsections within this chapter do not contain separate references.

7.1 Fish Community Sampling

Background

The monitoring of fish communities in the Lower Columbia River Estuary has been an integral component of the LCEP Estuary Monitoring Program (EMP) since its inception in 2008. Over the years, fish sampling methods, sampling frequency, and site locations have evolved to adapt to changing research priorities and environmental conditions. Notably, fish collections were initially conducted using the Puget Sound beach seine from 2008 to 2017 and subsequently transitioned to a 30-meter variable mesh bag seine in 2018. Sampling frequency ranged from 1 to 12 months per year, with accessibility and environmental factors, such as weather, water levels, and temperatures, influencing the scheduling of sampling events. The selection of sampling sites has shifted within the lower Columbia River, spanning from Rkm 6 to 221, to align with evolving project objectives. These methods draw from established protocols documented by Roegner et al. (2009), Schwartz et al. (2019), and Kidd et al. (2022) in various EMP reports.

Objective

The primary objective of these fish sampling methods is to generate a comprehensive and robust time series of data on fish communities within wetland habitats, applicable to areas such as the Columbia River Estuary and beyond. While there is a special emphasis on understanding the habitat utilization patterns of juvenile salmon, a species of ecological and conservation significance, the scope of these methods extends to broader ecological studies. Monthly sampling, concentrated in the months of March through June, is designed to capture key data across various habitats. Additionally, a subset of Chinook salmon specimens is retained for more detailed analysis, encompassing genetic origin, prey sources and consumption, age and growth, and overall health assessments. This approach, while integral to the Ecosystem Monitoring Program (EMP), is also adaptable to other similar environmental monitoring and research initiatives.

Materials

- Small boat (e.g., 17 ft Boston Whaler or 9 ft inflatable raft)
- 37-meter Puget Sound beach seine (PSBS; 37 x 2.4 m, 10 mm mesh size) for the period 2008-2017
- 38-meter variable mesh bag seine (10.0 mm and 6.3 mm wings, 4.8 mm bag) since 2018
- Dip nets (4 inches x 6 inches, 6 inches x 8 inches)
- 5-gallon buckets, 12-gallon tubs
- Aerators
- Fish measuring boards
- Balance
- Waterproof datasheets or electronic tablet
- Fish identification books
- Individual fish labels
- Individual fish plastic bags
- Individual genetic vials with alcohol
- Individual genetic vial tags
- Small scissors
- Forceps
- Small cooler with freezer packs
- Anesthetic

Methods

The method for deploying the beach seine is adaptable to the available space for sampling:

- In narrow channels, the net is stretched entirely along the bank, and towlines are cast to the opposite bank. The ends of the net are retrieved by simultaneously pulling on the lines, sweeping the net across the entire channel.

- In areas with ample beach space, the seine is deployed by anchoring one towline on the beach, stacking the net next to the anchor, and then pulling the seine off the beach with a boat in a sweeping arc. The ends of the seines, once on the beach at the waterline, are retrieved evenly from both sides to guide the captured fish into the center bag.

In both cases, fish captured within the bag are transferred to buckets filled with in-situ water. Multiple sets of seine hauls may be performed at each sampling site per month, and battery-powered aerators may be employed during high-temperature conditions to ensure the well-being of captured fish.

For each sampling effort, detailed records are maintained, including:

- Sampling location
- Time of sampling
- Water temperature and oxygen levels
- Amount of net used (used to calculate the area swept for fish density calculations)

All non-salmonid fish are identified to the lowest taxonomic level possible, usually family or genus species, and then counted and released. For salmonid species other than Chinook, the first 30 individuals are measured (fork length, nearest mm) and weighed (nearest gram). Any remaining individuals are counted and subsequently released.

In the case of Chinook salmon, up to 30 individuals are randomly selected, euthanized in the field, and subjected to comprehensive measurements. These measurements include length, weight, and the application of an individual tag that records site, date, and a unique fish identification number. Additionally, a tissue sample, typically from the caudal fin, is collected from each fish for genetic analysis and stored in labeled vials. The fish, tagged and bagged individually, are placed on ice in a cooler.

If present, an additional 70 Chinook are anesthetized, measured, and held until fully recovered, after which they are released. Any additional Chinook encountered are counted and also released. All salmonids undergo a thorough check for adipose fin clips, other external marks, coded wire tags, and passive integrated transponder (PIT) tags.

Sacrificed Chinook salmon, retained for detailed analysis, are stored in a laboratory freezer until necropsy at the end of the sampling season. This comprehensive analysis encompasses:

- Genetic testing for stock identification
- Otolith examination for age and growth determination
- Stomach content analysis to assess prey sources and consumption patterns
- Lipid analysis to evaluate fish health and condition factors

Data Management and Analysis

Refer to Section 7.2 "Fish Community Analysis" for details on data management and analysis procedures.

References

These methods are also posted online at MonitoringMethods.org here Method ID 826. See section 7.8 for all references and resources.

7.2 Fish Community Analysis

Background

Since the commencement of the LCEP/Estuary Monitoring Program (EMP) in 2008, the program has undertaken systematic fish community sampling across diverse trend sites within the lower Columbia River. This comprehensive sampling initiative was initiated to support the core mission of the program,

which is to delve into the intricacies of the estuarine ecosystem and monitor the dynamics of fish populations over time.

Throughout the program's history, the selection of sampling sites and the timing of sampling events have exhibited a dynamic nature, mirroring the evolving research goals and objectives. This adaptive approach has allowed the program to effectively capture the nuanced responses of fish communities to changing environmental conditions, management interventions, and habitat alterations.

Objective

The primary objective of the fish sampling endeavors conducted within the LCEP/EMP is to systematically document and characterize fish communities that inhabit the myriad habitats of the lower Columbia River. This characterization involves not only identifying the species composition but also systematically analyzing year-to-year trends in fish habitat utilization across various strategic locations along the river.

By employing robust analytical techniques, the program aims to discern patterns and changes in fish community structure and diversity. These insights play a crucial role in enhancing our understanding of the estuary's ecological dynamics and in guiding adaptive management strategies that promote the long-term sustainability of fish populations and the overall estuarine ecosystem.

Materials

For detailed information regarding the materials utilized in the field collections for fish, please refer to Section 7.1 "Field Collections for Fish."

Methods

Fish Species Richness and Diversity:
For each site, fish species richness (S), representing the number of species present, and fish species diversity (H'), calculated using the Shannon-Weiner diversity index (Shannon and Weaver 1949), were determined by month and year. Fish species diversity (H') was calculated using the formula:

$$H' = -\sum(pi * \ln(pi))$$

Where: pi represents the relative abundance of each species, calculated as the proportion of individuals of a given species to the total number of individuals in the community.

Chinook Salmon Metrics:
For Chinook Salmon, catch per effort (CPE) and fish density were rigorously calculated. Catch per effort (CPE) provides insights into the efficiency of fish capture and is a critical metric for population assessment. Fish density, expressed as the number of individuals per square meter (m^2), is a fundamental measure for understanding the spatial distribution of Chinook Salmon within the study area.

Size-Frequency and Regressions:
For all measured fish, we conducted size-frequency analyses to understand the size distribution within the community. Additionally, size-at-date and size-weight regressions were performed to elucidate

growth patterns and relationships between size and weight, contributing to a comprehensive understanding of fish populations in the lower Columbia River.

By applying these diverse analytical methods, we gain a comprehensive perspective on the fish communities in the lower Columbia River, allowing us to assess their composition, diversity, and dynamics over time.

References

See section 7.8 for all references and resources.

7.3 Genetic Stock Identification

Background

Since the initiation of the Lower Columbia Estuary Partnership's (LCEP) Estuary Monitoring Program (EMP) in 2008, the program has utilized Genetic Stock Identification (GSI) techniques to investigate the origins of juvenile Chinook salmon inhabiting various habitats within the Lower Columbia River Estuary. The application of GSI in this context has been informed and refined by prior research efforts in the field. Noteworthy studies include those conducted by Manel et al. (2005), Roegner et al. (2010), and Teel et al. (2009), which have significantly contributed to the development and understanding of GSI methodologies.

Objective

The primary objective of employing GSI techniques within the EMP framework is to ascertain the specific stock of origin for a representative sample of Chinook salmon captured during each site visit. By identifying the genetic stock to which these individuals belong, researchers can gain valuable insights into the origins and migration patterns of juvenile Chinook salmon within the Lower Columbia River Estuary.

Methods

From 2008 to 2013, the EMP estimated juvenile Chinook salmon stock composition using a regional microsatellite DNA dataset, as established by Seeb et al. (2007). However, starting in 2014, stock composition estimation shifted to employing a Single Nucleotide Polymorphism (SNP) dataset. This SNP dataset incorporates baseline genetic data from spawning populations located throughout the entire Columbia River basin, as detailed in Hess et al. (2014).

To estimate the proportional stock composition of Lower Columbia River samples, the GSI computer program ONCOR (Kalinowski et al. 2007) was employed. ONCOR implements the likelihood model developed by Rannala and Mountain (1997). The probability of origin was assessed for several regional genetic stock groups, including but not limited to the Deschutes River fall, West Cascades fall, West Cascades spring, Middle and Upper Columbia River spring, Spring Creek Group fall, Snake River fall,

Snake River spring, Upper Columbia River summer/fall, Upper Willamette River spring, Rogue River fall, and Coastal OR/WA fall. It's important to note that the West Cascades and Spring Creek Group Chinook salmon are representative of Lower Columbia River stocks.

References

These methods are also posted online at MonitoringMethods.org here Method ID 948, Method ID 1356, Method 1332, Method 5446. See section 7.8 for all references and resources.

7.4 Otolith Collection and Analysis

Background

Since the establishment of the LCEP/Estuary Monitoring Program (EMP) in 2008, researchers have been using a unique and fascinating tool called otoliths to investigate Chinook Salmon in the Lower Columbia River Estuary. But what exactly are otoliths?

Otoliths are small, calcified structures found in the heads of fish. Think of them as tiny, natural "black boxes" that record a fish's life history. As fish grow, otoliths grow too, adding layers like rings in a tree trunk. These layers contain a wealth of information about the fish's age, growth rate, and even its journey through different habitats.

Objective

Our objective in collecting and analyzing otoliths is to delve deep into the life story of Chinook Salmon. By studying these miniature, mineralized records, we aim to understand how fast these fish grow and what that growth can tell us about the health of the ecosystem they inhabit (Chittaro et al. 2018).

Materials

- Crystal Bond
- 600 grit silicon carbide (e.g., from Buehler)
- 5.0 alumina oxide
- micropolish
- 1500 micropolishing pads
- Compound light microscope
- Camera (e.g., Leica DFC450)

Methods

Otoliths used for microstructural analysis were obtained from Chinook Salmon with fork lengths ranging from 35-111 mm (mean = 66 mm, SD = 14.4 mm). The processing procedures for otoliths closely

followed established methodologies, as described in Stevenson and Campana (1992), Chittaro et al. (2018), and Chittaro et al. (2020).

Specifically, left sagittal otoliths were embedded in Crystal Bond and polished in a sagittal plane using various slurries, including Buehler©'s 600 grit silicon carbide, 5.0 alumina oxide, and 1.0 micropolish, along with a grinding wheel equipped with Buehler© 1500 micropolishing pads. The polishing process continued until the core of the otolith was exposed, allowing for the visualization of daily increments (Volk et al. 2010, Chittaro et al. 2015) under a light microscope.

Photographs of the polished otoliths were captured using a digital camera (Leica DFC450) mounted on a compound microscope (Zeiss©). Two essential measurements were taken from each otolith:

1) **Otolith radius at the time of capture (Oc):** This measurement provides crucial information about the otolith's current status and growth rate.

2) **Otolith radius at seven days before capture (Oa):** By measuring this parameter, we gain insights into the otolith's size seven days prior to capture.

To estimate the fork length at seven days before capture (La), we utilized the Fraser-Lee equation:

$$\mathbf{La = d + (Lc - d) / Oc}$$

Where:

- **d** represents the intercept (3.98 mm) of the regression between fish length and otolith radius ($R^2 = 0.81$, n = 855).
- **Lc** signifies the fork length (mm) at capture.

The average daily growth rate (mm/day) for an individual's last seven days of life (a) was then calculated using the formula:

$$\mathbf{Average\ daily\ growth\ rate = (Lc - La) / a}$$

The selection of seven days for growth estimation is particularly relevant in estuarine habitats, given the varying durations that Chinook salmon may inhabit estuaries, depending on factors such as migratory type (i.e., ocean-type vs. stream-type) and timing of migration (i.e., sub-yearling vs. yearling migrant). These factors result in salmon potentially residing in estuaries for weeks or even months (Healey 1991, Thorpe 1994, Weitkamp et al. 2014).

In our analysis, a generalized linear modeling (GLM) approach was employed to investigate the extent to which variability in somatic growth rate (the dependent variable) was explained by a comprehensive suite of independent variables. These independent variables encompassed collection year and day, river discharge, off-channel distance, river kilometer, genetic stock, hatchery or unmarked classification, and fork length.

River kilometer and off-channel distance denote the distance (km) of a site from the mouth of the Columbia River and the distance (m) between a site and the Columbia River channel, respectively.

Classification as "hatchery" was assigned to individuals with clipped fins or coded wire tags, while "unmarked" was assigned to fish lacking such markings. The term "unmarked" is preferred over "naturally produced" or "wild" because some hatcheries do not clip fins or inject coded wire tags, or they may mark only a fraction of their releases (Sagar et al. 2013).

All statistical models employed a gamma family distribution with a log link to account for the data's positive but non-normally distributed nature. The inclusion of the day of the year in our analyses addressed the nonlinear relationship observed between growth rate and this temporal variable. Additionally, fork length was integrated into our analyses to account for the linear relationship between growth rate and fish size. We systematically evaluated all possible GLM model combinations of the independent variables.

For model comparison, we calculated four key values for each model:

1) **Akaike's Information Criterion (AIC):** Smaller AIC values indicate superior models.
2) **Delta AIC:** Measures the difference in AIC values between competing models.
3) **Relative Likelihood:** Represents the likelihood of a model given the data.
4) **AIC Weight:** The discrete probability of each model.

In the evaluation process, the "best" model was identified as having a delta AIC of 0.00. However, preference was accorded to the simplest model when two or more models exhibited a delta AIC of less than 2 (Akaike 1973; Burnham & Anderson 2002).

These comprehensive analyses serve to unravel the intricate relationships between somatic growth rate and an array of environmental and biological factors, offering valuable insights into the life histories of Chinook Salmon within the Lower Columbia River Estuary.

References

The monitoring protocol can be found on monitoringmethods.org (Method ID 1593). See section 7.8 for all references and resources.

7.5 Fish Lipid Determination and Condition Factor

Background

Since the inception of the LCEP/Estuary Monitoring Program (EMP) in 2008, researchers have been conducting lipid analysis on retained Chinook Salmon. Lipids, a diverse group of organic compounds, play a crucial role in the health and well-being of salmon. They are not only a valuable energy source but also affect contaminant uptake and toxicity within these fish (Elskus et al. 2005). Various studies have highlighted the relationship between lipid content and the concentration of lipophilic chemicals responsible for toxic responses (Lassiter and Hallam 1990; van Wezel et al. 1995). In organisms with higher lipid content, a significant proportion of hydrophobic compounds binds to lipids, rendering them less available to cause toxicity. While lipids can help sequester toxins and protect fish from contaminants, an excess of lipids can disrupt buoyancy regulation during early ocean entry and potentially increase vulnerability to surface predators (Weitkamp 2008).

Objective

To determine the total, non-volatile, extractable lipid (reported as percent lipid) and lipid class content in Chinook salmon whole bodies. This assessment is essential for understanding the health and condition of salmon populations in the Lower Columbia River Estuary, as lipid content can serve as an indicator of their overall well-being. Additionally, it informs research related to contaminant uptake, toxicity, and the potential effects of lipid content on buoyancy regulation and susceptibility to predation during early ocean entry.

Materials

- Accelerated solvent extractor
- Sample tubes and vials
- Thin sections
- Extraction cells
- Silica Rod (e.g., Chromarod)
- Chromatography tank
- Microscope
- Drying agents (sodium sulfate and magnesium sulfate)
- Dichloromethane
- hexane:diethyl ether:formic acid (ratio of 60:10:0.02)

Methods

1) **Sample Preparation:** Whole-body samples from salmon collected in the field are grouped into sets containing 3-5 fish each, based on genetic reporting group, collection date, and site.

2) **Homogenization:** Composited salmon whole-body samples (approximately 2 g) are homogenized.

3) **Extraction:** The homogenized samples are mixed with drying agents (sodium sulfate and magnesium sulfate), packed into extraction cells, and extracted with dichloromethane using an accelerated solvent extractor.

4) **Sample Collection:** The extracts are collected into pre-cleaned and pre-weighed sample tubes.

5) **Determination of Total Lipid Content:** Approximately 1-2 mL of sample extract is transferred to a pre-weighed sample vial. The total, nonvolatile, extractable lipid content (reported as percent lipid) is determined by gravimetric analysis, following the procedure outlined in Sloan et al. (2014).

6) **Lipid Class Analysis:** Another sample extract aliquot (1-2 mL) is transferred to a second pre-weighed sample vial for lipid class analysis, which includes sterol esters/wax esters, triglycerides, free fatty acids, cholesterol, and phospholipids/polar lipids. This is achieved using thin-layer chromatography–flame ionization detection (TLC–FID) as described in Ylitalo et al. (2005) and Sloan et al. (2014).

    - Each sample extract is spotted on a silica rod (Chromarod) and developed in a chromatography tank containing a 60:10:0.02 hexane:diethyl ether:formic acid (v/v/v) solvent mixture.

- The different lipid classes are separated based on their polarity and measured using flame ionization detection, with the mean of two measurements taken.

7) **Calculation of Lipid Class Contributions:** The percent contribution of each lipid class to the total lipid is calculated by dividing the concentration of each lipid class by the total lipid measured.

Fulton's Condition Factor Calculation (C):

For all salmonid species, we calculate Fulton's condition factor (C) as an indicator of fish health and fitness using the following formula:

C = [weight (g) / (fork length (mm))^3] x 10,000

References

The monitoring protocol can be found on monitoringmethods.org (Method ID 952). See section 7.8 for all references and resources.

7.6 Salmon Diet

Background

Since the inception of the LCEP/Estuary Monitoring Program (EMP) in 2008, a critical component of understanding the ecological dynamics of the Chinook Salmon population has been the analysis of their stomach contents. Investigating the diet of juvenile Chinook Salmon provides valuable insights into their foraging habits, prey preferences, and broader ecological interactions within the Lower Columbia River Estuary.

Objective

The primary objective of salmon diet analysis is to elucidate the dietary composition of juvenile Chinook Salmon inhabiting the estuary. By comprehensively identifying and quantifying the various prey items consumed, this analysis sheds light on the trophic relationships and feeding patterns of this ecologically significant species.

Materials

The materials required for conducting salmon diet analysis include:

- Chinook Salmon specimens collected during field surveys.
- 10% formalin solution for preserving stomach samples.
- Laboratory equipment for processing and analyzing stomach contents, including dissecting tools, microscopes, and precision scales.

Methods

Salmon diet analysis involves a sequence of field and laboratory procedures:

***Field Data Collections**:*

1) **Collection**: When juvenile Chinook Salmon are captured at monitoring sites, they are euthanized within an hour of collection to preserve their stomach contents accurately.

2) **Storage**: The collected fish are kept on ice until they reach the NOAA field station laboratory. Here, they are stored in a -80°F freezer to maintain the integrity of the stomach contents.
3) **Necropsy**: At the end of the sampling season, necropsies are performed on the Chinook salmon bodies.
4) **Sample Preservation**: Whole stomach samples are extracted and preserved in 10% formalin. These samples are stored until they are ready to be transported to the laboratory for in-depth analysis.

***Laboratory Methods**:*

1) **Sample Examination**: In the laboratory, the preserved stomach contents are examined under a microscope. Organisms found in the diets are identified, typically to the family level. In some cases, identification may be more specific, such as to order or genus, particularly for crustaceans.
2) **Quantification**: Each prey taxon encountered in the stomach contents is meticulously counted, blotted on tissue paper to remove excess preservatives, and weighed with precision, often to the nearest 0.0001 gram.
3) **Data Compilation**: The data collected during the analysis are compiled systematically, recording the species, families, or orders of prey organisms, along with their respective quantities and weights.
4) **Digestion Assessment**: It's important to note that some stomach contents may be unidentifiable due to partial digestion. This aspect is also documented to provide a comprehensive understanding of the diet.

References

The monitoring protocol can be found on monitoringmethods.org (Method ID 1593). See section 7.8 for all references and resources.

7.7 PIT Tag Arrays

Background

Passive Integrated Transponder (PIT) systems represent a pivotal technology in the realm of aquatic ecology and fish tracking. These systems function by detecting the presence of an individually coded PIT tag through the generation of an electromagnetic field. One of the key advantages of PIT arrays is their capacity for self-sustainability and continuous, unattended operation, making them a highly attractive means for monitoring the presence and movement of juvenile salmon in diverse wetland habitats.

PIT tags, each possessing a unique individual code, offer precise identification of a single fish, including details about its rearing history and release data. This feature enables the comprehensive tracking of individual fish throughout the complex hydrological network of the Columbia River.

The deployment of PIT tag detection systems has been instrumental in enhancing our understanding of fish ecology. Over time, from 2011 to 2019 and in the year 2022 and beyond, these systems have been strategically placed in vital locations, including Campbell Slough within the Ridgefield Wildlife Refuge and the confluence of Horsetail and Oneonta Creeks with the Columbia River. The continued evolution of PIT systems mirrors advancements in technology, ensuring the effectiveness and reliability of these critical monitoring tools.

The fundamental components of a typical PIT system include:

- **Multiplexing Transceiver:** This unit records and stores tag detections, forming the core of the data acquisition process.

- **Antennas:** These may be ridged or flexible and are crucial for transmitting and receiving signals. They play a pivotal role in detecting PIT tags as fish pass through the system.

- **Power Source:** Powered by a series of batteries, often supported by solar panels, this element ensures the continuous operation of the PIT system, even in remote or unattended locations.

- **Platform and Waterproof Box:** These components protect the delicate electronics of the PIT system from environmental factors such as water, debris, and wildlife.

The number and configuration of antennas are determined by the specific channel profile at the deployment site. Typically, antennas are positioned vertically within the channel to maximize coverage of both water depth and channel width, ensuring a comprehensive detection field. Despite their many advantages, it's important to note that PIT tag systems are not without challenges. They are susceptible to various environmental setbacks that can adversely affect their operations, including cable breakages due to rodents or debris, excessive debris loads damaging antennas, inadequate battery charging during low-light or winter periods, flooded electrical components, and wear and tear caused by high water flows and ship wake surges.

Figure 23: Types of PIT Systems deployed at sites.

Objective

In the context of the EMP project, the installation of PIT tag detection systems serves a specific purpose. These systems are strategically deployed to complement the fish seining efforts undertaken within the project. By doing so, they significantly enhance the dataset available for analysis, providing valuable insights into the types and timing of salmon stocks utilizing the wetland areas of interest.

Materials

The materials required for the implementation of PIT tag detection systems include:

- Multiplexing Transceiver
- Batteries
- Solar Panels
- Antennas
- Waterproof Electronics Box
- Platform

Methods

The design and installation of PIT tag systems are highly adaptable and tailored to the unique characteristics of the waterways in which they are deployed. It is imperative to closely follow the manuals and guidelines provided by the manufacturers of the electronic equipment chosen for installation. Regular site visits are essential to conduct visual inspections and perform necessary maintenance to ensure the uninterrupted and accurate functioning of the PIT tag detection systems.

Data Management and Analysis

Data downloaded from the PIT tag transceiver form a crucial dataset for analysis. These data can be efficiently uploaded to the Columbia Basin PIT Tag Information System (PTAGIS), serving as the centralized database for PIT-tagged fish within the Columbia River Basin. By following the provided instructions, a comprehensive tag history can be acquired, encompassing critical information such as species, stock, origin, release location and date, and previous detection locations. This database is instrumental in expanding our understanding of fish migration patterns, stock dynamics, and the overall health of the aquatic ecosystem.

References

The monitoring protocol can be found on monitoringmethods.org (Method ID 826). See section 7.8 for all references and resources.

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8. Considerations for Data Management

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Background

While data management tends to be a very personal thing, this working document is intended to inform both new and seasoned research scientists about tips and tricks for saving time and improving the usability and ease of sharing data and repeating analyses. This section is very general because there is no single right answer; each project will have its own requirements and best strategies.

In this section, carefully consider the monetary costs of the software, the time and energy to learn the new software, and the repeatability, speed, and efficiency of the software.

Field Data

The primary data management strategy begins with recording field data while in the field. Use either Rite-in-the-Rain paper or a waterproof electronic method to record all notes. The specifics of what needs to be recorded varies day to day; however, always include a date, time, and location as well as a brief explanation of what was done (Figure 24). It can help to create data sheets beforehand for consistency across monitoring events (Figure 25). Lastly, transfer all field notes to an electronic format immediately after returning from the field by utilizing either a scanner or simply taking a picture of the page.

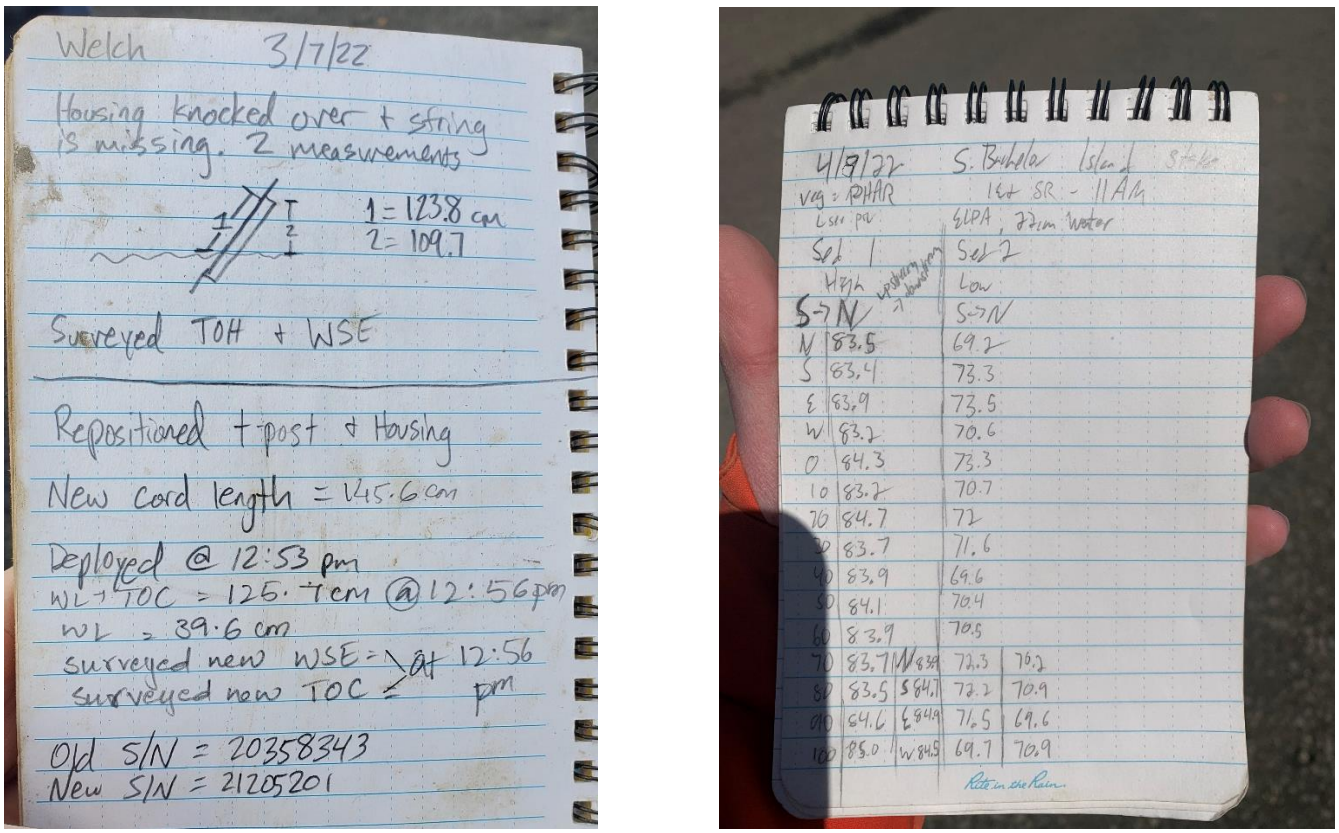

Figure 24: Example field notes from a logger retrieval and redeployment (left) and a sediment accretion bench install (right). Both field notes were entered into appropriate spreadsheets at the end of the field day.

DATE: 7/21/21 SITE: Welch PLOT#: LS TIME: 8:30 SAMPLERS: IEAS TOTAL # OF BAGS: 4

	DOMINANT SPECIES 1		DOMINANT SPECIES 2		OTHER SPECIES											
LIVE/DEAD (L/D)	Live	Dead	Live	Dead	LIVE / DEAD	L	L	L	L						BARE GROUND	DETRITUS
USDA PLANT CODE	SALA		ELPA		USDA PLANT CODE	BOLT	ELCA	LEDE	LIAM							
% COVER	70		50			10	1	1	1						5	10
NUMBER OF BAGS					OTHER LIVE # Bags:			OTHER DEAD # Bags:								
HIEGHT (CM)	94		90		Notes:											
WATER	(Y) N		30%		DEPTH (cm): 2.5											
SOILS	ORP: 47 Salin 75.1				pH: 7.04 TEMP: 18.7 °C CONDUCTIVITY: 160.8											

Figure 25: Example data sheet for biomass recording. This was entered into the appropriate spreadsheet at the end of the field day.

Metadata

Each project should have overall metadata associated with it ranging from locations, types of monitoring it is receiving, and the locations, dates, and type of each monitoring action.

At the Estuary Partnership, we have designed a relational database within Tableau. We have two distinct types of metadata tables (Figure 26). The first is an overall estuary wide table containing broad information on every single site that behaves as the unifying table. The second format involves a table for each type of monitoring action and contains the location and date of each action. The action specific metadata directly relates to each database. We also have a third table that contains a site-specific data log of locations for where the data is stored, what was collected and when, maps of the site, and other general site notes.

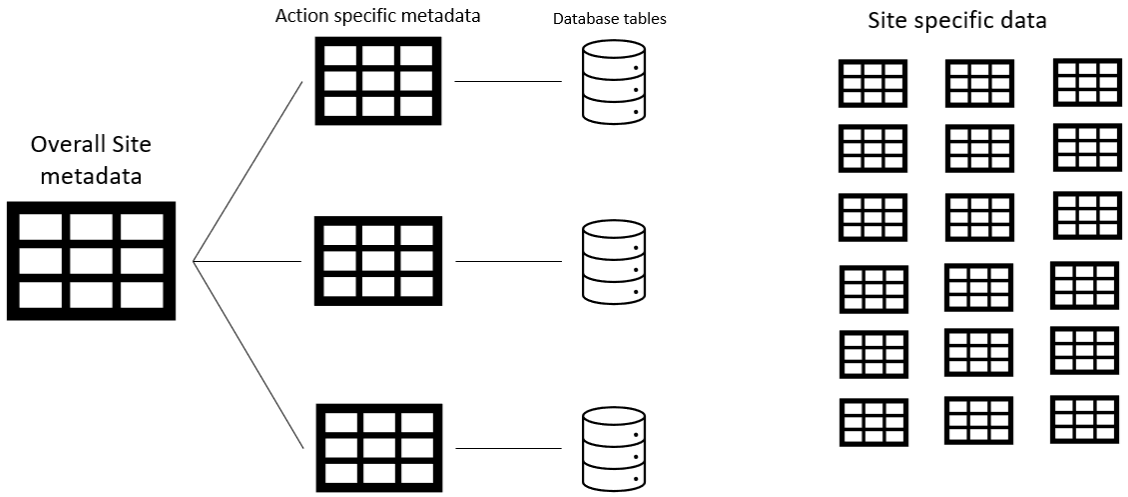

Figure 26: Data structure of the Estuary Partnership's data.

Data Storage

Data storage is vital if one wants to do anything with the information collected. When first creating a data warehouse, think critically about the effects of the format as the warehouse grows. Additionally, consider software requirements and how the data will be analyzed. For example, if there is a possibility of the data exceeding the limits of excel, do not store the data in a single excel page. Alternatively, if one is interested in analysis in R, store the data in a format compatible with that. Some options for data storage include SQL relational databases (e.g., Microsoft Azure, Amazon Athena, DolphinDB, etc.), CSV files, and tableau hyper files; each option has pros and cons particularly for monetary cost, storage/spatial considerations, as well as speed/temporal efficiency when pulling data from the warehouse.

Overall data storage is one of the most pivotal aspects of any project and critical thinking about the format prior to having impossible-to-handle spreadsheets will save hundreds of hours down the line.

Data Analysis

Data analysis can be conducted in a variety of ways; however, it is recommended to use a repeatable option. A repeatable method is something like a script where upon updating the data warehouse, the script will simply read and perform the same analysis with more data, without any extra work from the analyst. Some software options that allow for repeatable analysis include Tableau, Excel Pivot Tables, ESRI Arc Online, R, Python, and SQL queries.

Ensure all methods are recorded for future analysists building upon previous work. Utilize detailed instructions, comments, appropriately named variables, and well-thought-out file names and structure.

Tableau Software

Tableau is a user-friendly data visualization software that is capable of processing, summarizing, and displaying large quantities of geospatial (and non- geospatial) data. It is an interactive platform that encourages data exploration by researchers and allows the target audience to both follow the story presented by the analysist and explore the data themselves.

Tableau 2022.2 can store and query vast quantities of data in a user-friendly manner. It requires no knowledge of any coding to start, making it extremely quick and easy to pick up and use; however, if one is more coding inclined, Tableau allows for one to directly write advanced queries and analyses in a variety of languages including SQL, Python, and R. Additionally, Tableau is built for collaboration. Multiple people can connect to and analyze the same datasets and seamlessly contribute back to the same workbook. Furthermore, all tableau work is often easily modifiable each year as one collects more data or adds additional sites to the analyses. One simply needs to update the base database (e.g., adding another six months of measurements to a hydrology database) and the graphs, plots, and analyses will all automatically update with the additional data.

While there are multiple tiers of the software ranging from free to paid with various privacy options, Tableau can and does meet most of the Estuary Partnership's needs for data QA/QC, analysis, and visualization. We, at the Estuary Partnership, utilize Tableau Desktop for most of our base work; Tableau Online to host our data and collaborate with fellow researchers; Tableau Prep Builder to quickly check and prepare our data for analysis; and Tableau Public to publish our work to the world at large. Of these, Tableau Public is completely free while Tableau Desktop and Prep Builder can have minimal annual costs. The online space varies in cost depending on the number of users and quantity of data required.

We have publicly disseminated multiple datasets and analyses including our hydrology, vegetation, sediment accretion, drone analyses, macroinvertebrates, fish, and other datasets and analyses in the form of Tableau dashboards; often designed to accompany reports. These dashboards provide an opportunity for project sponsors, researchers, and other interested parties to visualize and self-explore the evolution of the restoration site from pre-monitoring to its current state as well as share and communicate these results to landowners, project managers, and other members of the public in an easily digestible manner.

See this tableau link for an example of the AEMR dashboards created to date.

9. Monitoring Protocol Conclusions, Considerations, and Next Steps

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[1] Lower Columbia Estuary Partnership

In the realm of evaluating restoration projects, the significance of effective monitoring protocols cannot be overstated. These protocols are not just guidelines; they are blueprints for prioritizing funding, gauging treatment efficacy, and predicting the timeline of project outcomes. This working document serves as a compass for both new and experienced research scientists embarking on the path of comprehensive monitoring.

Our journey through these protocols has underscored the indispensable role of consistency in rendering monitoring data truly useful. It's not just a matter of accuracy—it's the cornerstone of reliable data analysis and statistically sound comparisons. Yet, data collection alone does not suffice; data management is its steadfast companion. The lack of proper records risks rendering research irreproducible. The safekeeping of both physical and electronic records is paramount, safeguarding the essence of our endeavors.

The practicalities of implementation come to the forefront. Customized field data sheets and a strategic approach to scanning and data entry counteract the potential of data loss. Yet, these methods extend beyond individual efforts. Recognizing the inevitability of personnel shifts, a broader strategy must be conceived to maintain consistency between agencies and researchers.

Harmonization of measurement units cannot be overlooked. A seamless marriage of imperial and metric units, even with good intentions, introduces the risk of erroneous recordings. The seemingly innocuous interplay of measurement tools can lead to data fragility. The need for meticulous unit selection, both in data collection and gear usage, is irrefutable.

However, in our pursuit of consistency, we must also recognize the virtue of adaptability. Monitoring is not a static endeavor; it's an evolving process that must be tailored to the unique demands of each project. Adapting protocols to align with specific project needs, shifting circumstances, and unforeseen challenges is an art. The data we gather is not merely a snapshot; it's a narrative that informs adaptive management. By consistently analyzing the data's patterns and trends, we can make informed decisions that steer the course of ongoing restoration efforts.

As we draw these protocols to a close, the message is clear: flexibility is the heartbeat of effective monitoring. Adaptability should be our steadfast ally, guiding us to fine-tune protocols in response to project evolution. But this should never eclipse the twin virtues of consistency and intentionality. By embracing these principles, we ensure the replicability and comparability of our efforts across diverse sites.

This is not a mere conclusion; it's a call to action. In a dynamic world, our protocols must evolve in step with the terrain we navigate. The torch we pass on to future researchers should illuminate their path with clarity, precision, and an unwavering commitment to preserving our environment's vitality.

In recognizing the expansive scope of environmental monitoring and restoration, it is essential to understand that the principles and practices outlined in this document, while informed by specific programs like the CEERP, have universal applicability. The broader environmental context in which we operate requires that our monitoring protocols be adaptable and relevant across various ecosystems and projects. The Lower Columbia Estuary Partnership's commitment to fostering a holistic approach to ecosystem management underscores the need for protocols that are not only robust and reliable but also flexible enough to be applied in diverse environmental conditions and studies. This perspective ensures that our work, while grounded in specific programs and studies, contributes to a larger body of knowledge and practice in environmental conservation and restoration.

Next Steps:

The journey doesn't end here. Monitor the field's progress and welcome innovation. A protocol is not static; it's a living entity that grows and refines with each contribution. Seek feedback, incorporate advancements, and expand the horizons of what's achievable. As we embark on new restoration challenges, armed with these protocols, let our actions echo our commitment to a healthier, thriving ecosystem. Through adaptive management informed by meticulous monitoring, we can usher in an era of sustainable restoration and preservation.

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