

Nearshore Habitat Status and Trends Monitoring to Support Puget Sound Salmon Recovery (20-1941P):

*Tidal Restriction and Tidally Influenced Habitat Extent Mapping for Puget
Sound's Nearshore – Final Report*



*Image: Shoreline along Eagle Harbor at Bainbridge Island.
Photo Credit: Department of Agriculture, NAIP imagery 2023.*

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EXECUTIVE SUMMARY

Tidally influenced nearshore and estuary habitats can provide critical rearing and migration habitats for juvenile salmon, and their conservation and restoration has been identified as a priority for the recovery of Endangered Species Act (ESA) listed salmon in the Puget Sound (Beamer et al. 2005; Beamer et al. 2018). However, the ability to identify restoration opportunities and track progress towards recovery (restoration) on a regional scale has been limited, as many existing datasets describing tidal restriction features (e.g., dikes and levees, roads and railways, shoreline armor, docks and piers, and water crossing features) are incomplete (i.e., mapping does not cover the entire region or is specific to one area, only certain feature types are included like roads, or data set does not include a complete spatial inventory and is missing features), outdated (i.e., datasets were developed in different years and do not represent the same time period or current conditions), fragmented across organizations (i.e., different jurisdictions like diking districts maintaining their own separate datasets), inconsistent methods or attributes (e.g., some datasets include detailed elevation and physical data, information on materials used for culverts or dikes, and some datasets focus on specific feature types like roads or just water crossing features). Previous mapping projects have identified significant data gaps in the completeness of regional datasets mapping nearshore tidal restriction features and tidally influenced habitats. Significant progress was made in developing a consistent spatial database of tidal restriction and tidally influenced habitats for Puget Sound's large river deltas (Hall et al. 2021; WRCO 2019a; [ESRP Project #18-2250](#)). However, there was still a need to synthesize and standardize regional datasets for the rest of the Puget Sound nearshore. This project (WRCO 2019b; [ESRP Project #20-1941P](#)) addressed this data gap by extending the previously completed mapping of large river delta tidal restriction features to the rest of the Puget Sound, thereby developing consistent and updated regional mapping data for tidal restrictions (e.g., levees, dikes, floodgates, culverts, etc.) and tidally influenced habitat extents for Puget Sound nearshore habitats.

We compiled data from 49 local, state, and federal datasets, including 267 vector layers mapping infrastructure, water crossings, hydrology, nearshore wetland and estuary habitat, land cover, and elevation data. We reviewed and reconciled these data with aerial imagery to create a consistent, up to date, and complete spatial database of Puget Sound nearshore tidal restrictions mapped as polylines and tidal influenced habitat mapped as polygons. Tidal restrictions features were classified by primary feature type (e.g., roads, railways, dikes/levees, armor) and water crossing feature types (e.g., bridges,

culverts, floodgates, docks/piers) and crossing types (e.g., ocean, streams/rivers, no visible channel). Restrictions were further classified by their impact on tidal connectivity (e.g., unrestricted, partially restricted, significantly restricted, and completely restricted tidal connectivity) based on their feature type and status (e.g., present or removed). We used the 2022 draft Pacific and Marine Estuarine Partnership Potential Wetland Extents to delineate areas within potential tidal influence based on elevation (PMEP 2022) and used our mapped tidal restriction network to segment and assign connectivity classifications to the potential tidally influenced habitat extent. We initially attempted to classify potential tidally influenced embayment and lagoonal habitat types into functional or geomorphic classifications (e.g., barrier lagoons, closed lagoons, etc.). However, it was determined (through regional review) that additional coordination is needed to develop a consistent classification schema to support regional salmon recovery planning and evaluation. Therefore, we focused on classification of potential tidally influenced habitat extents based on tidal connectivity ratings in this phase of the project.

As a result of this project, we have mapped 3,149 kilometers of tidal restriction features, including 363 kilometers of water crossing features, and 174,150 hectares of tidally influenced habitat using regional data and remote sensing for the Puget Sound nearshore. This represents newly mapped areas outside of previously mapped large river deltas ([ESRP Project #18-2250](#)). Although the large river deltas mapped as part of our previous project ([ESRP Project #18-2250](#)) are not included in this report, they are summarized in Hall et al. (2021) and the datasets are presented together in a WDFW hosted [ArcGIS web map](#). Among the tidal restriction features (polylines) mapped as part of this project, we mapped and classified a total of: 2,705 kilometers of complete tidal restrictions, 12 kilometers of significant tidal restrictions, 334 kilometers of partial tidal restrictions, 28 kilometers of unrestricted crossings, 70 kilometers of restrictions with unknown impacts, and 8,256 water crossing features (Figure 1). We note that among the water crossing features mapped, approximately 7.8% were not previously included in regional data sources and were identified using aerial imagery. We also mapped 293 kilometers of primary features (10% of the total length) that were not previously mapped in the regional data. This represents a significant improvement in the completeness of regional data describing tidal restriction features.

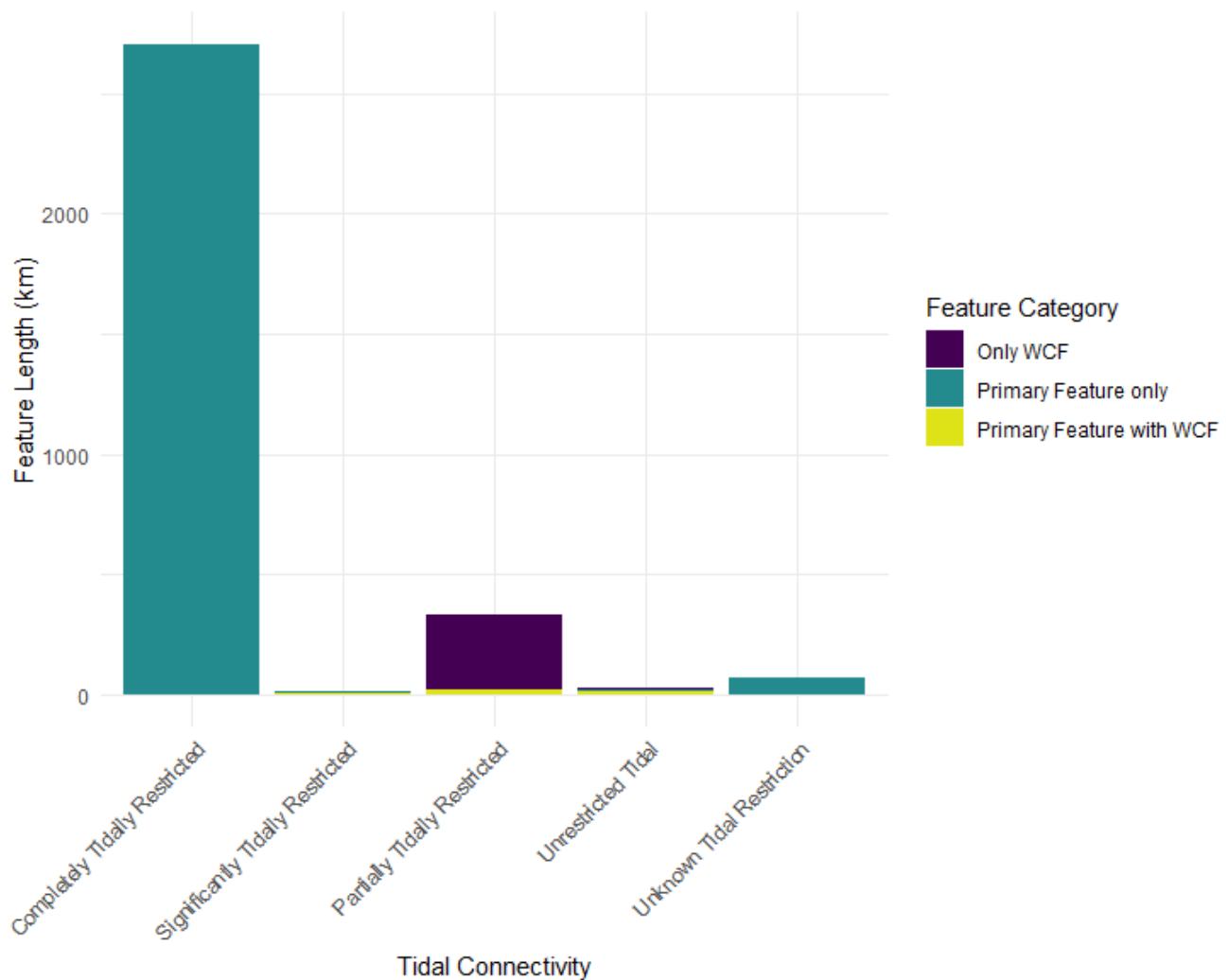


Figure 1. Summary of tidal restriction feature lengths for primary features (e.g., road, railway, dike, levee etc.) without a water crossing features (WCF) (e.g., bridge, culvert, tide gate, etc.), primary features with WCFs, and WCFs without a primary feature type (e.g., isolated culvert in an agricultural field).

Of the 174,150 hectares of mapped tidally influenced extent (polygons), we classified a total of: 1,438 hectares of completely restricted non-tidal habitat, 211 hectares of significantly restricted tidal habitat, 347 hectares of partially restricted tidal habitat, 10,192 hectares of unrestricted tidal habitat, and 209 hectares of habitat with unknown tidal connectivity (Figure 2). Additionally, we mapped 161,470 hectares of nearshore extent that included deep and shallow intertidal habitat up to 304 m seaward of the shoreline.

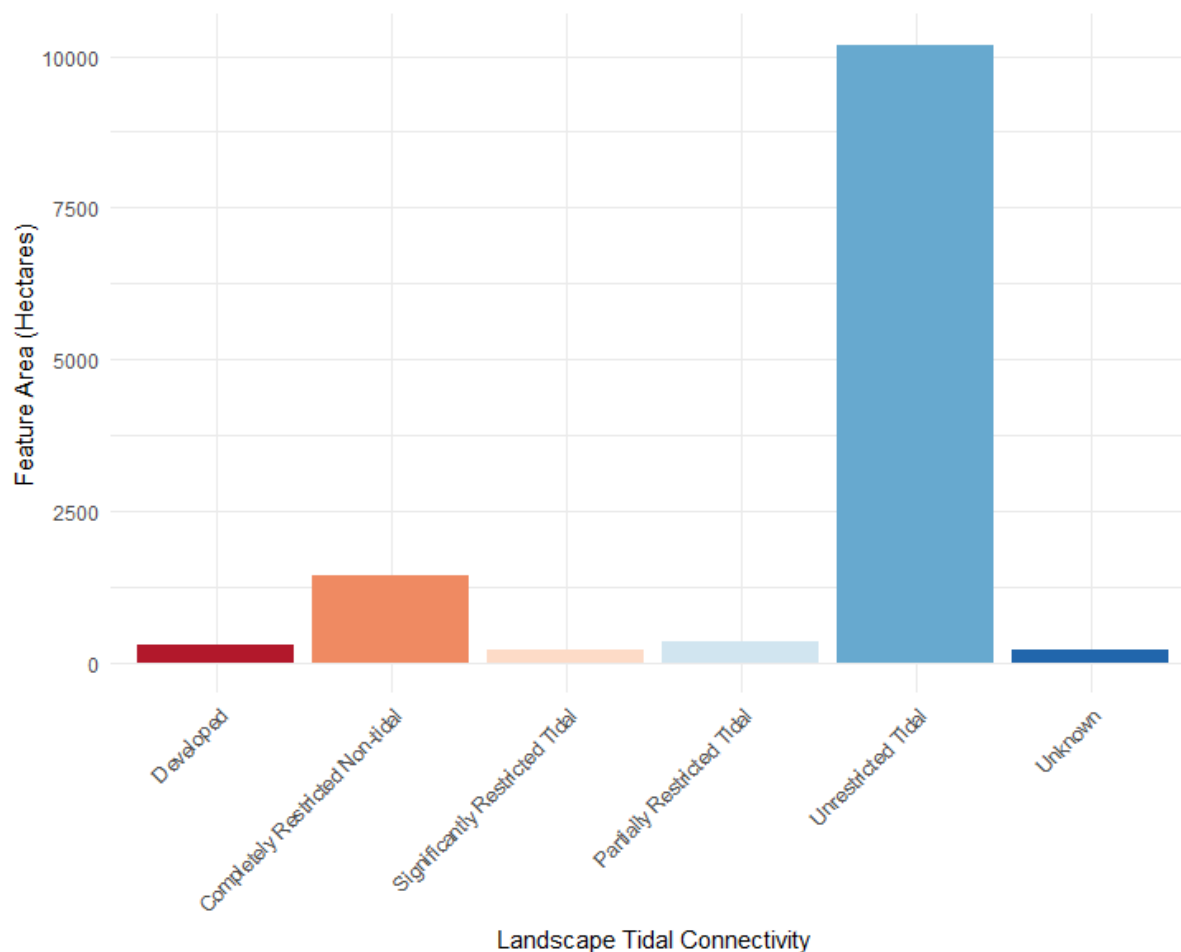


Figure 2. Summary of area by connectivity ratings for polygons of potential tidally influence extent, which were delineated and assigned based on the mapped tidal restriction network for the Puget Sound shoreline (excluding large river deltas). Developed areas and areas classified as completely restricted non-tidal are assumed to be non-tidally influenced habitats, while unrestricted, partially restricted, and significantly restricted tidal habitats represent a gradient of tidal connectivity based on the mapped tidal restriction network. Unknown connectivity was assigned when the connectivity could not be determined based on regional data or remote sensing.

As part of our mapping efforts, we worked with Lead Entity (LE) groups and regional data stewards, practitioners, and salmon recovery co-managers to review the accuracy and completeness of a draft dataset. This was a critical step in our approach, and we received a total of 93 comments from regional reviewers from which 41 features were updated in the datasets to reflect their feedback. However, we note that there are still unknown features and features with low certainty that could be addressed by additional or continued regional review. In addition, it is important that we work with regional partners and workgroups (e.g., the Puget Sound Partnership, the Puget Sound Ecosystem Monitoring Program (PSEMP) Spatial Data and Nearshore workgroups, and LEs) to develop protocols for updating and maintaining the dataset and integrating information from ongoing regional reviews.

The final datasets produced as part of this project have been published in coordination with the WDFW to an [ArcGIS web map](#), which also includes the previously developed large river delta datasets. This web map can also support continued regional review to address unknowns and changes over time. In addition, making these data publicly available supports restoration planning (such as identifying or prioritization of restoration opportunities), and regional habitat status and trends monitoring and evaluation of progress towards recovery (e.g., Puget Sound Partnership Vital Sign Indicators, Progress Indicators, and Salmon Habitat Indicators) to a broad audience of practitioners and co-managers.

CONTENTS

Executive summary.....	i
Introduction.....	7
Methods.....	9
Study Area	9
Regional data discovery and processing	12
Standardized spatial database	14
Tidal restrictions	14
Tidally influenced extent	18
Data review and validation	24
Compiling and sharing final spatial databases.....	24
Results and Findings	25
Regional data synthesis.....	25
Tidal Restrictions	25
Tidally Influenced Extent	29
Regional review	30
Discussion.....	32
Applications and next steps	34
References.....	38
Appendix A: Data Discovery Log	44
Appendix B: Mapping methods and data structure.....	50
Tidal restriction regional data processing and mapping	50
Delineating potential tidally influenced extent	58
Data structure.....	59
Appendix C: Results	71
Appendix D: Digitizing Methods.....	78
Appendix E: Proposed Decision Tree for habitats.....	82

List of Figures

Figure 1. Summary of tidal restriction feature lengths for primary features (e.g., road, railway, dike, levee etc.) without a water crossing features (WCF) (e.g., bridge, culvert, tide gate, etc.), primary features with WCFs, and WCFs without a primary feature type (e.g., isolated culvert in an agricultural field).	iii
Figure 2. Summary of area by connectivity ratings for polygons of potential tidally influence extent, which were delineated and assigned based on the mapped tidal restriction network for the Puget Sound shoreline (excluding large river deltas). Developed areas and areas classified as completely restricted non-tidal are assumed to be non-tidally influenced habitats, while unrestricted, partially restricted, and significantly restricted tidal habitats represent a gradient of tidal connectivity based on the mapped tidal restriction network. Unknown connectivity was assigned when the connectivity could not be determined based on regional data or remote sensing.	iv
Figure 3. Map showing the nearshore tidal restriction and potential tidal influence mapping extent, based on the Beach Strategies Nearshore Geospatial Framework (NGF) 0-200 ft buffer (CGS 2017) and a 200-ft landward buffer of the 2022 draft PMEP extent (shown). Tidal restrictions and tidally influenced extents within the SHSTMP large river delta geomorphic tidal floodplain boundaries (Beechie et al. 2017) (shown in light blue) have already been mapped as part of our previous effort (ESRP Project #18-2250, Hall et al. 2021).	11
Figure 4. Overview of potential shoreline and tidally influenced extent buffers that were used to define our mapping extent. Tidal restrictions were mapped from the shoreline (as determined from aerial imagery) to the Beach Strategies Nearshore Geospatial Framework (NGF) 0-200-ft landward extent (where applicable), and within the potential tidal influence polygons (from PMEP and manually digitized tidal influence extent) and a 200-ft buffer landward. Tidal restrictions were attributed to identify where they fell within these extents (seaward aerial imagery, Beach Strategies NGF 0-200-ft, PMEP, PMEP 0-200-ft buffer).	12
Figure 5. Flow chart for classifying tidal connectivity ratings for tidal restrictions. Features were first identified as a primary and/or water crossing feature, and then their tidal connectivity was determined based on the status of the feature (present, abandoned, breached, removed). Rules for classifying unrestricted features were updated based on the results from review from regional experts and the technical advisory group.	17
Figure 6. Example of tidally influenced extent categorized by landscape connectivity.	22
Figure 7. Flow chart for assessing the features' tidal connectivity and landscape tidal connectivity for tidally influenced extents.	23
Figure 8. Proportion of tidal restriction features by tidal connectivity rating for each Lead Entity area (see Figure 3), excluding previously mapped large river deltas.	28
Figure 9. Proportion of area by landscape connectivity rating for each of the Lead Entity areas (see Figure 3). Nearshore deep and shallow were excluded to focus on potential tidally influence extent landward of the shoreline and within embayment features. The Nisqually Lead Entity Area was mapped completely in the Large River Deltas (ESRP Project #18-2250) and was not included.	30
Figure B.10. Example of armor and railways mapped in the regional data along the Puget Sound nearshore and how the lines were synthesized in the updated shoreline tidal restriction database. ...	55
Figure B.11. Examples of the mapped water crossing feature types. 1) A channel spanning bridge classified as unrestricted. 2) A single breached levee section classified as a partial restriction. 3) A	

culvert classified as a significant restriction. 4) A non-channel spanning bridge classified as a partial restriction. 5) A SRT classified as a significant restriction. 6) A floodgate classified as a complete restriction. 56

List of Tables

Table 1. Reference geospatial layers used for mapping tidal restrictions and tidally influenced habitat extent.	13
Table 2. Feature type classifications for primary feature and water crossing feature types, with water crossing features being nested within a primary feature type. Descriptions adapted from Greene et al. (2017) and (2013).	16
Table 3. Connectivity ratings used for tidal restriction features. These classifications were based on the approach used in the lower Columbia River estuary for mapping and classifying tidally influenced extents based on tidal restriction features and function (LCEP 2009).	18
Table 4. Description of tidally influenced extent polygon features mapped in this project.	19
Table 5. Landscape and feature connectivity classifications for non-nearshore tidally influenced extents. See Figure 7 for decision tree.	20
Table 6. Length of tidal restriction features (kilometers) by feature type, source, and connectivity rating for Puget Sound (excluding large river deltas that were previously mapped). For length by source, regional data indicates that the feature was in regional datasets, while aerial imagery indicates the feature was not included in regional data and was manual digitized from aerial imagery. Regional reviewer indicates that the feature was mapped based on regional reviewer comments. WCF = water crossing feature.	27
Table A.7. Web data portals examined to identify available datasets for the large river delta and nearshore tidal restriction and habitat features. This is not a complete list of data sources as other data were directly downloaded from regional data stewards. Hyperlinks to the web portals are shown in blue and bold. Downloaded refers to if data were downloaded and used from the portal. NA means the data were unavailable.	44
Table A.8. Datasets used in the tidal restriction mapping project. Dataset names, the number of layers, a data description, spatial coverage and reported years of data collection are all included. This table is not complete and new datasets will be added as they are delivered. A (-) refers to unknown.	46
Table B.9. Status used to describe tidal restriction primary and water crossing features.	57
Table B.10. Data form for CFS tidal restriction inventory. All features were digitized into a geopackage, and the following data was retained for them.	59
Table B.11. Data entry form for CFS tidally influenced extent inventory. All tidally influenced extent features were digitized into a geopackage and a geodatabase, and the following data were retained.	64
Table B.12. Data entry form for data reviewers. Reviewers filled out the following using a password protected Arc Online Data portal using a unique login that tracked reviewer name and date of review.	70
Table C.13. Total feature lengths (kilometers) for primary (e.g., road, boat ramp, armor/fill, etc.), primary with water crossing feature (WCF) (e.g., road with a culvert, etc.), and only WCF by connectivity impacts for nearshore tidal restrictions (excluding the large river deltas) in the LE areas. Primary features classified by if they were armored, if they were along a waterfront or PMEP boundary but armor wasn't present or wasn't visible, NA refers to features that were not immediately adjacent to or intersecting the PMEP area.	73

Table C.14. Total lengths (kilometers) of tidal restrictions grouped by their tidal connectivity rating for each LE area.....	76
Table C.15. Feature area (hectares) of nearshore tidally influenced extent (excluding the large river deltas and nearshore shallow and deep extents) by LE Area and landscape connectivity impacts.	77

List of Acronyms

C-CAP	Coastal Change Analysis Program
CRS	Coordinate Reference System
CRW	Chinook Recovery Watershed
CUSP	NOAA's Continually Updated Shoreline Product
DEM	Depth Elevation Model
DNR	Department of Natural Resources
DOE	Department of Ecology
EBEEM	Elevation-based estuary extent model
ESA	Endangered Species Act
ESRI	Environmental Systems Research Institute
ESRP	Estuarine and Salmon Recovery Program
FPDSI	Fish Passage and Diversion Screening Inventory
GIS	Geographic Information Systems
HRLC	High-resolution Land Cover
LE	Lead Entity
LiDAR	Light Detection and Ranging
MHHW	Mean higher high water
NAIP	National Agriculture Imagery Program
NGF	Nearshore Geospatial Framework
NHD	National Hydrography Dataset
NOAA	National Oceanic and Atmospheric Administration
NWFSC	Northwest Fisheries Science Center
PMEP	Pacific and Marine Estuarine Fish Habitat Partnership
PS	Puget Sound
PSEMP	Puget Sound Ecosystem Monitoring Program
PSNERP	Puget Sound Nearshore Ecosystem Restoration Project
PSP	Puget Sound Partnership
RTK	Real time kinematic GPS
SHI	Salmon Habitat Indicator (PSP)
SHSTMP	Salmon Habitat Status and Trends Monitoring Program
TAG	Technical Advisory Group
USGS	United States Geological Survey
VS	Vital Signs (PSP)
VSP	Viable Salmon Population
WDFW	Washington Department of Fish and Wildlife
WRIA	Watershed Resource Inventory Areas

INTRODUCTION

Puget Sound's large river deltas and tidally influenced habitats associated with the rest of Puget Sound's nearshore (e.g., lagoons, embayments, and other tidal wetland habitats) provide critical rearing, saltwater transition, and migration corridor habitats for juvenile salmon (Beamer et al. 2005; Beamer et al. 2018, Quinn 2018). Conservation and restoration of estuarine and tidally influenced habitats have been identified as top priorities for regional salmon recovery efforts in Puget Sound, especially for Endangered Species Act (ESA) listed Chinook Salmon populations, which depend on estuarine and nearshore habitats for juvenile rearing, refuge, and transition to marine life stages (Simenstad et al. 1983; Simenstad and Cordell 2000; Beamer et al. 2005; Bottom et al. 2005a; Bottom et al. 2005b; Quinn 2018). The area of functional (tidally connected and accessible) tidally influenced habitat is a regional salmon habitat indicator for large river deltas, pocket estuaries, and embayments in Puget Sound (see Puget Sound Partnership (PSP) Vital Sign and Salmon Habitat Indicators). Restoration of tidal connectivity or removal of features that block or restrict tidal processes represents a significant opportunity to increase functional and accessible tidally influenced habitat. However, the ability to identify restoration opportunities and track progress towards recovery (restoration) on a regional scale has been limited, as many existing tidal restriction datasets are incomplete (i.e., mapping does not cover the entire region or is specific to one area, only certain feature types are included like roads, or data set does not include a complete spatial inventory and is missing features), outdated (i.e., datasets were developed in different years and do not represent the same time period or current conditions), fragmented (i.e., different jurisdictions like diking districts maintaining their own separate datasets), or inconsistent (e.g., some datasets include detailed elevation and physical data, information on materials used for culverts or dikes, and some datasets focus on specific feature types like roads or just water crossing features).

Many local, regional, state, and federal agency datasets have mapped tidal restriction, tidally influenced, or tidal wetland features and habitats (e.g., Simenstad et al. 2011; Beechie et al. 2017; PMEP 2018; Brophy et al. 2019; Confluence 2019; Ramirez 2019a; Stefankiv et al. 2019; WDFW 2020). However, these datasets differ in structure, extent, resolution, and the types of features mapped, and none of these existing datasets integrate tidal restriction features with associated tidally influenced habitats. Furthermore, regional datasets have been created for a variety of purposes and are therefore difficult to integrate, standardize, and use collectively at regional scales. A consistent database mapping tidal

restrictions, their type and connectivity impacts, and how these features influenced tidal connectivity to potential tidally influence habitats at a regional scale was a significant data gap for the Puget Sound region. This data gap limited our ability to develop regional-scale recovery planning data to support restoration planning and evaluation as well as evaluation of progress towards recovery, and we have directly addressed this data gap with completion of this project.

For the purposes of this project, **we defined tidal restrictions as human-made features (e.g., levees and dikes, roads and railways, and water crossing features like bridges, piers and docks, tide and floodgates, and culverts) that can disrupt, mute, or restrict tidal and floodplain functions, including flood storage and conveyance, nutrient processes, and hydrologic, sediment, wood, and biotic movement** (adapted from Konrad 2015). The degree to which tidal processes are influenced varies among and within feature types depending on a number of physical factors (e.g., feature dimensions, elevation, landscape position, tidal and riverine processes). Regional recovery planning and evaluation programs (like those the [Salmon Habitat Status and Trends Monitoring Program](#) or the [PSP Vital Signs and Salmon Habitat Indicators program](#)) rely on delineation and characterization of current and potential tidally influenced habitats, including the degree to which tidal connectivity is restricted, at both regional and system scales. These data are needed to: (A) to develop meaningful recovery goals and targets; (B) identify, evaluate, and prioritize restoration opportunities; and (C) evaluate progress towards recovery goals and targets over time. This relies on consistent and accurate regional scale mapping that requires comprehensive identification of tidal connectivity restrictions.

Significant progress was made in developing a consistent spatial database of tidal restriction and tidally influenced features through [ESRP Project #18-2250](#) for Puget Sound's large river deltas. For that project, we used a combination of regional data and remote sensing to synthesize and correct regional data and map missing features followed by regional review with local area experts and field validation surveys. We found that our approach was efficient in creating a consistent, standardized, and up to date spatial database of tidal restriction features for Puget Sound's large river deltas while also identifying and mapping many features missing from available regional datasets ($\approx 45\%$ of the mapped features were not included in regional data). This project leveraged the already compiled regional datasets, standardized spatial database for the large river deltas, and remote sensing protocols to map tidal restriction features and tidally influenced extents for the rest of the Puget Sound shoreline. We worked with agencies, co-managers, and stakeholders to develop spatial data products that integrate with

existing habitat status and trends monitoring programs and metrics, address regional data gaps, and are readily accessible through online mapping applications to support restoration planning and evaluation of progress towards recovery and habitat restoration at a regional scale. This report serves as the final report for [ESRP Project #20-1941P](#) and provides a summary of the methods to compile regional data and map tidal restriction and tidally influenced habitat extents, results and findings at both regional and Lead Entity (geographic areas that are used to report the status and trends of habitat in the Puget Sound region) reporting area scales, and appendices with supporting information on the methods and results.

METHODS

Study Area

Previous mapping efforts (Hall et al. 2021) focused on delineating tidal restrictions within the Salmon Habitat Status and Trends Monitoring Program (SHSTMP) large river delta boundaries (NOAA 2016; Stefankiv et al. 2019) and tidally influenced extents in the Puget Sound Ecosystem Monitoring Program (PMEP) tidal exceedance polygons within the deltas (PMEP 2018; Brophy et al. 2019). This effort aimed to map tidal restrictions and tidally influenced extents for the remainder of the Puget Sound shoreline outside of the previously mapped large river deltas. While we compiled information at a regional scale, we also report summaries by Lead Entity (LE) areas, which are similar to Puget Sound sub-basins and counties but are grouped by stocks within a watershed. The LE areas are managed by a Lead Entity group for salmon recovery plans in Washington state. Out of the 25 LE areas in Washington state, we mapped within the 15 LE areas throughout the Puget Sound.

To define the mapping extent with respect to the extent of tidal influence and proximity to the shoreline, in our previous mapping effort (Hall et al. 2021), we used the 2018 PMEP tidal exceedance dataset (Brophy et al. 2019) as the tidally influenced extent, and we first considered this dataset given that it provided coverage for the rest of the Puget Sound. However, there were inconsistencies in coverage for smaller tidally influenced embayments, lagoons, and other features. We worked with PMEP to address this issue, and they provided an updated layer in 2022 to improve coverage of these features and published a draft spatial dataset that we used for this mapping effort. We found that the updated draft 2022 PMEP extent vastly improved the coverage of pocket estuaries and embayments identified in the PSP Common Indicators dataset (PSP 2019; Hall et al. 2019). However, some features were still missing or misaligned and we used the Pocket Estuaries point dataset (PSP 2019; Hall et al. 2019) to identify tidally influenced habitats not captured in the updated 2022 PMEP dataset, and used aerial imagery and

elevation data (DEMs) to delineate the extent of those habitats along the Puget Sound shoreline. To complement regional datasets and to capture features that could influence tidal connectivity or processes in tidally influenced habitats, we also mapped restrictions within four nearshore strata, 1) seaward to the Nearshore Geospatial Framework (NGF) shoreline which is based on the WA DNR ShoreZone shoreline, 2) within the Beach Strategies NGF 0-200 ft polygon, 3) within the PMEP extent or aerial imagery-mapped extent, and/or 4) within a 200-ft buffer of the PMEP or aerially imagery mapped tidal exceedance extent (Figure 4). It is important to note, that with the draft 2022 PMEP extent was used as our basis of mapping represents the modelled maximum extent of tidal flooding based on current topography and extreme tidal water levels, what we describe as potential tidally influenced habitat extent (completely restricted non-tidal), does not represent historical extent. The elevation models were derived from modern datasets and already integrate some degree of fill and development in the landscape (PMEP 2018; Brophy et al. 2019).

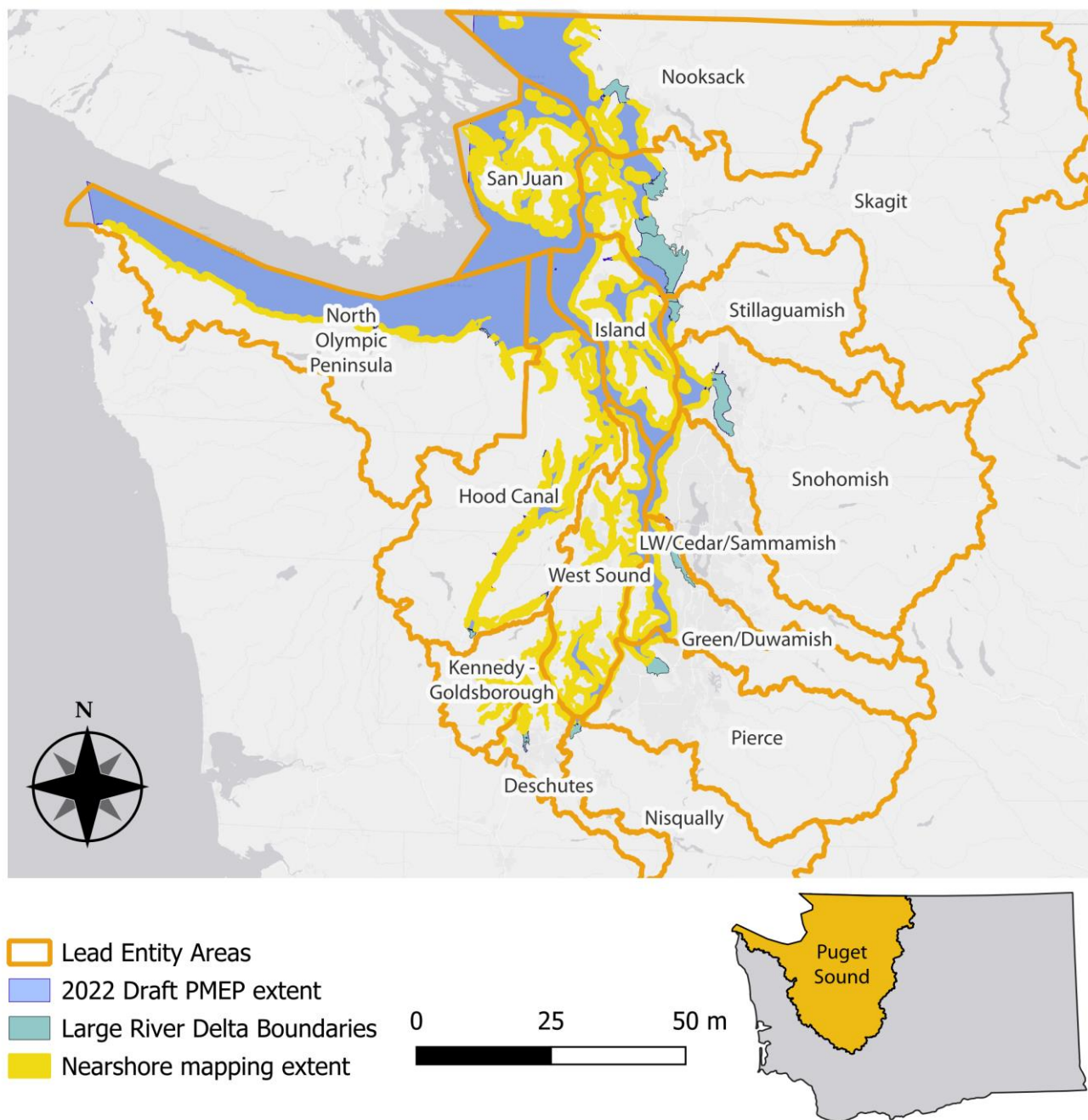


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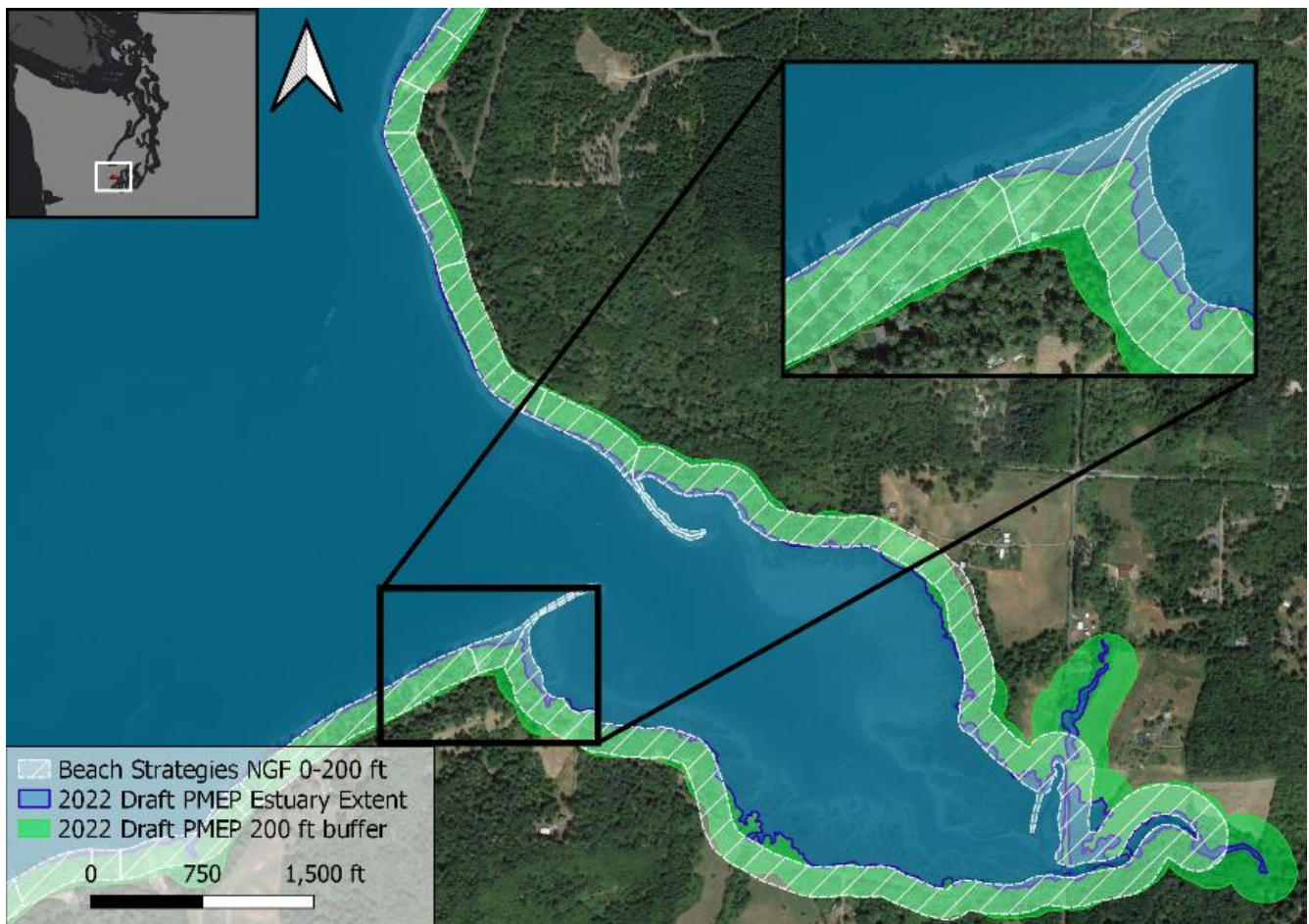


Figure 4. Overview of potential shoreline and tidally influenced extent buffers that were used to define our mapping extent. Tidal restrictions were mapped from the shoreline (as determined from aerial imagery) to the Beach Strategies Nearshore Geospatial Framework (NGF) 0-200-ft landward extent (where applicable), and within the potential tidal influence polygons (from PMEP and manually digitized tidal influence extent) and a 200-ft buffer landward. Tidal restrictions were attributed to identify where they fell within these extents (seaward aerial imagery, Beach Strategies NGF 0-200-ft, PMEP, PMEP 0-200-ft buffer).

Regional data discovery and processing

In our previous project ([ESRP Project #18-2250](#)), we compiled spatial datasets that contained habitat, infrastructure, and hydrography data for estuarine and delta habitats from online sources and direct requests to regional data stewards, with an emphasis on data that describe features that block or potentially mute tidal connectivity. These data were also considered in this effort, but we performed additional data queries to identify any sources that may have been published since or missed in our initial search. We developed an archive of all compiled regional data layers as part of this project, but a summary of the regional data layers compiled and consider in this study are provided in Table 1 and Appendix A: Data Discovery Log.

Table 1. Reference geospatial layers used for mapping tidal restrictions and tidally influenced habitat extent.

Source	Dataset	Description	Dates
DNR	Shorezone shoreline	Region-wide shoreline that describes physical and biological characteristics along Washington State's saltwater shorelines	2001
CGS	Beach Strategies Nearshore Geospatial Framework (NGF)	Polyline and polygon layers that provide updates to the DNR Shorezone shoreline that include geomorphic shoreform classifications and drift cells for the Puget Sound	2017
NOAA	Continually Updated Shoreline Product (CUSP)	Continuous shoreline polyline dataset frequently updated for the continental U.S.	1992-2021
Google Earth	Aerial imagery	Provides time series of aerial imagery that can be used to evaluate riparian cover for a given year.	Historic - 2022
NAIP	Aerial Imagery	Provides high resolution (1 meter) 4-band aerial imagery of the continental US a	2009-2021
DOE	Coastal Atlas oblique shoreline imagery	Provides an oblique aerial view for some portions of the nearshore Puget Sound that can be used to see shoreline and riparian features	2006-2007, 2016-2017
Earth Views	360 'Street View' Nearshore Imagery	Provides kayak collected high resolution imagery of the Puget Sound nearshore including riparian vegetation cover	2020-2021
3DEP	Hillshade DEM	Provides information on the presence and topology of shoreline features where features are obscured by cover or shadows	Varies
WDNR	DTM	LiDAR derived Digital Terrain (DTM) and Digital Surface Models with spatial resolution of up to 3-feet	Varies
PSP	Pocket Estuaries	Point locations of pocket estuaries mapped using aerial imagery.	2019
San Juan County	Pocket Estuaries	Point locations and polygons of pocket estuaries and habitat	2014, 2018
PMEP	Tidal Exceedance polygons	Provides the expected range of tidal influence and informs the potential and current wetland extent based on current topography. Updated in 2021 to improve mapping of pocket estuary and embayment habitats.	2018, 2021

We used QGIS (QGIS 2024) to visualize and process all regional datasets. The fix geometry tool was used to address any geometry errors in the compiled datasets, and we used a unique ID using the dataset name and row number was given to every row of every dataset to track features for future data processing. This identifier can be used to link features included in the final database to the original data source, which may contain useful information that can be reviewed and accessed. Data were projected to a common coordinate reference system (CRS), WA State Plane South NAD 83 HARN (EPSG 2927) and saved as geopackage file (a QGIS layer package that allows for storage of large datasets of multiple geometries and data types) and geodatabase file (similar to a geopackage, this file type is for ESRI products). A data inventory was maintained with names and descriptions of all data discovered including the source, file type (e.g., GIS shapefile or geodatabase), spatial extent, data year, access date, permissions, and a summary of the data included. The data type (e.g., vector: line, point, or polygon, or raster) was also recorded.

Standardized spatial database

Variations in data structure, accuracy, and extent limited the utility of available datasets at a regional scale, and this highlighted the need for a consistent regional database structure and remote-sensing based synthesis approach. As part of the ESRP [Project #18-2250](#), we developed protocols that created a new data structure that streamlined information, geometry, and attribution for mapping tidal restrictions and tidally influenced extents in the Puget Sound large river deltas (WRCO 2019, Hall et al. 2021). For mapping tidal restrictions and tidally influenced extents along the Puget Sound nearshore, we utilized the same general data structure to ensure compatibility between the datasets but made key updates to capture characteristics specific to the shoreline and nearshore, which are described in this report (see also Appendix B: Mapping methods and data structure). We synthesized available regional data sources into our spatial database for both tidal restrictions and tidally influenced extent datasets, with attributes that described feature types (for tidal restrictions, primary and water crossing structure, tidal connectivity impacts, key physical information, and the spatial location of the feature (e.g., study extent strata, shore type, drift cell, and Lead Entity boundary). The database structures were also designed to capture information on the source of mapped features (e.g., regional data, remote sensing, regional review, or field validation), and to document corrections or updates identified using remote sensing, field validation, or regional review to features mapped in a regional dataset. In addition, we created attributes to flag features for field and/or local area expert review and validation, as well as certainty ratings for feature type and connectivity to support review, interpretation, and updating of the database. The full data structure and descriptions of attributes and values in the standardized database are described in more detail in Appendix B: Mapping methods and data structure.

Tidal restrictions

All tidal restriction features were digitized as polylines with a single line representing the approximate elevational top or middle of the tidal restriction feature. Digitizing included the following key steps: (1) synthesizing redundant features and correct spatial alignment, (2) updating removed or modified features, (3) digitizing missing features, (4) classifying feature types and certainty, and (5) classifying tidal connectivity and certainty. Features were classified using regional data and/or aerial imagery in a two-tiered nested structure that included a primary feature type and water crossing feature type (where applicable) as described in Table 2. The first tier included roads and railways, dikes and levees, armored or filled banks, footpaths, and boat ramps, which were classified as primary feature types. The second tier included water crossing structure type, if applicable. Water crossings were defined by the presence

of connectivity or flow under a solid feature as identified by aerial imagery or as mapped in the regional data. If for a given line segment, the primary feature was not also a water crossing, the water crossing type was reported as NULL (e.g., a section of road without culverts or other water crossing structures). If the water crossing was not part of a primary feature (e.g., agricultural bridges and culverts without a graded road), then the primary feature was classified as NULL. If a water crossing existed, the line feature was segmented into a separate feature (using the mapped regional data location and aerial imagery as reference) to the full extent of the crossing and the segment was classified by the primary type (e.g., roads, railways, dikes, levees, armored banks) and the water crossing feature (e.g., floodgates, self-regulating tide gates (SRTs), culverts, docks and piers, bridges and causeways). However, primary features with multiple paths were only segmented once for the water crossing feature (e.g., railways with multiple tracks) to prevent overinflation of water crossing feature lengths and counts. Additionally, water crossing features were attributed with their crossing type as “Stream/River,” “Ocean,” or “Not visible/unknown,” and by the stream name, if applicable. Lengths of water crossing features were summarized by their transecting length as mapped with polylines. Features were then classified by their impacts on tidal connectivity, with intact primary features being classified as complete tidal restrictions, and water crossings being classified as unrestricted, partial, significant, or complete tidal restrictions based on their feature type and status using a rule-based classification (Figure 5 and Table 3).

Table 2. Feature type classifications for primary feature and water crossing feature types, with water crossing features being nested within a primary feature type. Descriptions adapted from Greene et al. (2017) and (2013).

Type	Feature	Description
Primary feature	Dike/levee	Dikes are narrow earthen walls built to reduce tidal inundation, while levees are similar structures built in freshwater floodplains to impede flood flows. These structures are designed to block tidal or riverine floods onto uplands or to create uplands from intertidal/floodplain areas.
	Road/Railway	Roads are hardened and often raised substrates or embankments that are similar in design to dikes and levees. Road embankments are also commonly built along coastal bluffs or at the edges of geomorphic floodplains or tidal deltas.
	Unmapped road/footpath	Unpaved and agricultural roads and paths which were not included in the road database are delineated and classified as Unmapped roads. Unmapped roads are presumed to disrupt tidal and floodplain functions, including hydrologic, sediment, wood, and biotic movement to some extent. Footpaths were also included in these features but mapped as unknown connectivity impacts. These features were flagged for further evaluation as it was difficult to discern their impacts on tidal connectivity from the aerial imagery and reference data.
	Armored/filled	Bank armoring includes nearshore and freshwater stream armoring, such as boulders, riprap, seawalls, and breakwaters, which are designed to reinforce banks and bluffs and protect them from erosion or flooding. Filled areas are identified where earthen or engineered fill appeared to raise the restriction above the flooding elevation.
	Boat ramp	Boat ramps were identified as mapped in the regional data or by the imagery as stable structures (e.g., concrete, wood, rock) that extend into the nearshore to allow nearshore access.
	Null	Water crossing features present with no associated primary feature, such as foot bridges or farm culverts with bridges without a graded road.
Water crossing feature	Bridge, causeway	Bridges and viaducts include features that fully span tidally influenced floodplains and tidal channels and features constructed with piers, abutments, open-bottom vaults, or arches that support the structure but extend into the waterway or floodplain. Channel spanning bridges and viaducts are often associated with roads and railways, while bridges and causeways built in conjunction with fill, dikes, and armoring are often narrow and confine the waterway or tidal floodplain at the site of the crossing.
	Dock/OWS	Piers and docks were identified as structures extending partially or fully over water bodies or water ways, floating or built on pilings. These are also referred to as overwater structures (OWS).
	Floodgate and/or pump station	Floodgate, flapgate, and tidegate structures are culverts with fitted gates that are designed to drain freshwater on ebbing tides while blocking tidal flow during flooding tides. Pump stations were also grouped into this feature type since they are often associated with control structures that block tidal flow during flooding tides. Floodgates were identified if a gate was visible in the imagery or if mapped in the regional data.
	Self-regulating tide gate (SRTs)	Unlike floodgates, SRTs are designed to allow drainage from upstream of the structure while also providing some degree of tidal flooding into the area upstream of the structure, but the degree of connectivity varies with the design and physical and seasonal setting. SRTs can be built into larger gates to provide improved drainage, tidal flooding, or fish passage through a passive or manually controlled gate. SRTs were identified by the regional data or reviewers.
	Culvert	Culverts comprise a number of enclosed or semi-enclosed structures conveying tidal and fresh water both upstream and downstream under roads or through dikes, levees, road grades, trails, railroad grades, and other similar obstructions. Culverts varied widely in material, size, and shape, which impacts fish passage and connectivity
	Pipe	Pipes included buried pipes that are fully underground and enclosed pipes that are designed to transport flow, stormwater, and allow drainage from filled tidal areas.
	Open crossing	Crossings were classified as open if a primary feature was breached and flow was visible or a water crossing feature was removed and flow was visible
	Unknown	Features were classified as unknown when a water crossing was visible, but the feature type was not listed in the regional data could not be determined from the aerial imagery.
	Null	All primary features with no water crossing features present.

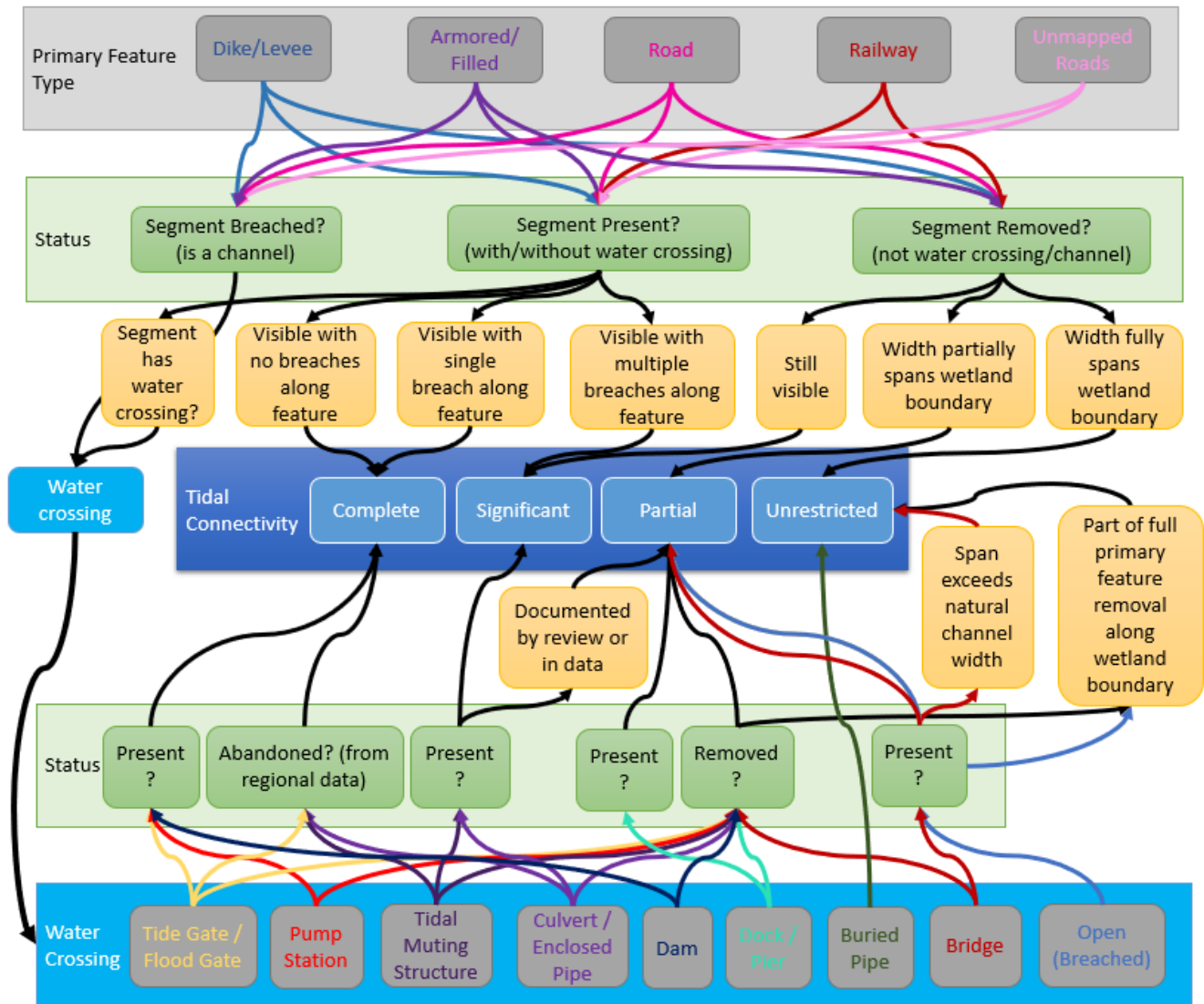


Figure 5. Flow chart for classifying tidal connectivity ratings for tidal restrictions. Features were first identified as a primary and/or water crossing feature, and then their tidal connectivity was determined based on the status of the feature (present, abandoned, breached, removed). Rules for classifying unrestricted features were updated based on the results from review from regional experts and the technical advisory group.

Table 3. Connectivity ratings used for tidal restriction features. These classifications were based on the approach used in the lower Columbia River estuary for mapping and classifying tidally influenced extents based on tidal restriction features and function (LCEP 2009).

Connectivity Rating	Description	Features
Unrestricted	Indicates that the feature does not impair tidal connectivity.	Bridges with spans exceeding the visible natural channel width, breaches and removed primary features where the removal spans the tidal floodplain boundary, buried pipes.
Partial Restriction	Indicates that the feature partially restricts tidal connectivity, but that most tidal processes are not significantly impaired.	Bridges with spans less than the natural channel width, individual breaches and removed features with the full width less than the natural channel width, docks and piers, SRT with connectivity determined by regional review or data.
Significant Restriction	Indicates that tidal processes and connectivity are present but significantly restricted or muted. Evidence of tidal flooding above the feature was often harder to detect in aerial imagery for significantly restricting features and therefore this classification often relied on feature type classifications.	Tidal muting structures, SRTs, Culverts, Enclosed pipes, Remnant or unmaintained levees with breaches.
Complete Restriction	Indicates that a feature completely blocks tidal connectivity and tidal processes. Impoundments and simple channel morphology above features with no apparent sign of tidally influenced habitat are used in combination with feature type information to inform this classification.	Intact primary features: levees, dikes, roads, railways, armored banks, boat ramps, floodgates, gravity drains and storm outfalls.
Unknown Restriction	This indicates that the connectivity impacts cannot be determined from remote sensing or the compiled regional data.	All features where feature type cannot be discerned. Footpaths were also classified as unknowns.

Tidally influenced extent

Polygons describing tidally influenced habitat extents were developed using the 2022 draft tidal exceedance polygons from Pacific Marine and Estuarine Fish Habitat Partnership (PMEP) and our mapped tidal restriction features. To exclude neritic and ocean zones from the PMEP extent, we clipped the tidal exceedance polygons to exclude areas that were 1,000-foot seaward of the Beach Strategies NGF shoreline. This buffer width was selected to include all potential tidally influenced extents and portions of shallow and deeper nearshore tidally influenced habitats that could potentially contain manmade tidal restriction features (e.g., docks and piers that extend seaward). We then ran a union function to segment the working PMEP wetland extent with the NWIFC Statewide Intertidal Areas dataset (NWIFC 2023), to classify intertidal areas into nearshore deep and shallow habitats as described in Table 4. The NWIFC dataset allowed us to define seaward boundaries whereas the PMEP provided us

with a landward boundary to use for mapping. Large river deltas mapped in the previous effort were also excluded from our mapping extent, and developed areas within the potential tidally influenced extent were delineated from aerial imagery similar to the methods developed in the delta mapping effort (Table 4). The remaining areas were classified generally as the potential tidally influenced extent, which were further segmented using the tidal restriction polylines and their connectivity classifications and landscape position (see Figure 6).

Table 4. Description of tidally influenced extent polygon features mapped in this project.

Feature	Connectivity	Definition
Nearshore Deep	Unrestricted or Partially tidally restricted	Seaward area within 1,000 ft of +1 m MHW line (derived from NOAA 3m bathymetry data clipped to the DOE and DNR shoreline (NWIFC 2023)) that had a depth of ≤ -4 m MHW. If Nearshore Intertidal area extends seaward $\geq 1,000$ ft, there will not be a mapped subtidal polygon for that section of shoreline, Nearshore Deep areas were assumed to have Unrestricted tidal connectivity unless between OWS feature and were assumed to be partially tidally restricted.
Nearshore Shallow	Unrestricted or Partially tidally restricted	Seaward areas within 1,000 ft of the landward boundary of intertidal extent (+1 m MHW that are within -4 to +1 meters MHW (derived from NOAA 3m bathymetry data clipped to the DOE and DNR shoreline (NWIFC 2023))). All features were assumed to have Unrestricted tidal connectivity, but note that overwater structures may influence tidal processes in these habitats.
Large River delta	Any	One of 17 large river deltas that were mapped as part of Phase I, see Hall et al. (2021).
Developed	Developed	Areas mapped in the PMEP but were filled or developed and not within tidally influenced extent.
Tidally Influenced Extents	Any	Features within PMEP extent but are not nearshore, which were segmented and classified by connectivity using the tidal restriction feature type and connectivity ratings.

Potential tidally influenced polygons were classified as unrestricted tidal, partially restricted tidal, significantly restricted tidal, completely restricted non-tidal, or unknown tidal connectivity habitats (Table 5). Similar to the tidal restriction feature connectivity ratings, we established a rule-based classification system to determine connectivity ratings that were based on the tidal restriction features that influence tidal connectivity to each polygon (Figure 7). To capture both the proximate as well as the landscape impacts of tidal restrictions, we classified each tidally influenced polygon according to its feature and landscape connectivity (Table 5). Feature tidal connectivity describes the connectivity of an individual polygon based on only the tidal restriction features that immediately surround or define the polygon perimeter (Figure 7). Landscape tidal connectivity considers the connectivity impacts of all the surrounding and downstream (or seaward) tidal restriction features that would impact tidal flow to the polygon (Figure 7). Figure 6 shows an example of the tidal restriction features and polygons mapped from those data, and the landscape connectivity ratings that were assigned based on the rules described in Table 5 and Figure 7. Detailed step-by-step GIS methods for developing tidally influenced extent polygons are included in Appendix D: Digitizing Methods.

Table 5. Landscape and feature connectivity classifications for non-nearshore tidally influenced extents. See Figure 7 for decision tree.

Landscape connectivity	Landscape connectivity	Feature Connectivity
Completely Restricted Non-tidal	Indicates that a feature completely blocks tidal connectivity and tidal processes. Impoundments and simple channel morphology above features with no apparent sign of tidally influenced habitat.	Tidally influenced extents upstream of or surrounded by complete tidal restrictions, such as dikes and levees, roads, railways, or completely restricted primary tidal restriction and water crossing features, were classified as completely restricted non-tidal. Areas with less restrictive landward or upstream tidal restrictions were still called completely restricted non-tidal if tidal connectivity to the area was restricted. Tidally influenced extents were also called completely restricted if the feature was surrounded by areas outside of the PMEP boundary.
Significantly Restricted Tidal	Tidally influenced extents directly upstream of significant tidal restrictions or upstream of a significantly restricted tidally influenced extents and upstream of an unrestricted, partial, unknown, or significant restriction were called significantly restricted.	Tidally influenced habitats that were surrounded by tidal restriction features that only allow for significantly impacted hydrologic and tidal connectivity, such as some SRTs, culverts, and enclosed pipes were classified as significantly restricted tidal.

Landscape connectivity	Landscape connectivity	Feature Connectivity
Partially Restricted Tidal	Tidally influenced extents directly upstream (landward) of partial tidal restrictions or upstream of a partially restricted tidally influenced extents were classified as partially restricted for landscape connectivity. All tidally influenced extents upstream of non-channel spanning bridges and breaches and removed features were called partially restricted for their landscape tidal connectivity rating, unless they were upstream of a more restricted tidally influenced extent, in which case their connectivity was determined by that extent's rating. Tidally influenced extents surrounded by OWS were called partially restricted, unless upstream of a significantly or completely restricted tidal restriction or tidally influenced extent.	Tidally influenced extents upstream of tidal restrictions with partially restricted connectivity were classified as partially restricted for feature connectivity based on the restriction features immediately surrounding the tidally influenced extent. This included tidally influenced extents upstream of breaches and bridges with spans less than the channel width, and SRTs restored to allow partially restricted tidal connectivity. OWS and tidally influenced extents surrounded fully by OWS were called partially restricted tidal.
Unrestricted	Tidally influenced extents were classified as unrestricted for landscape connectivity if all surrounding and downstream (seaward) extents were open to tidal flooding. Features upstream of tidally influenced extents were classified as unrestricted and with at least one unrestricted water crossing or removed primary feature (e.g., channel spanning bridges, breached primary and removed primary features) were classified as unrestricted.	Tidally influenced extents were classified as unrestricted tidal for feature connectivity if they were open to tidal flooding via at least one unrestricted feature. Extents with full primary feature removals along the boundary were classified as unrestricted. Areas located landward/upstream of channel spanning bridges that allow for tidal connectivity underneath the bridge were also classified as unrestricted. Extents with tidal restriction features along the landward or upstream boundary of the tidal influenced extent were still classified as unrestricted if at least one unrestricted feature was present allowing tidal connectivity to the feature.
Developed	Areas mapped in the PMEP but were filled or developed and often had visible overland structures such as houses were given a developed rating.	
Unknown	This indicates that the connectivity impacts cannot be determined from remote sensing or the compiled regional data. Features upstream of tidal restriction features with unknown connectivity restrictions were given an unknown rating.	

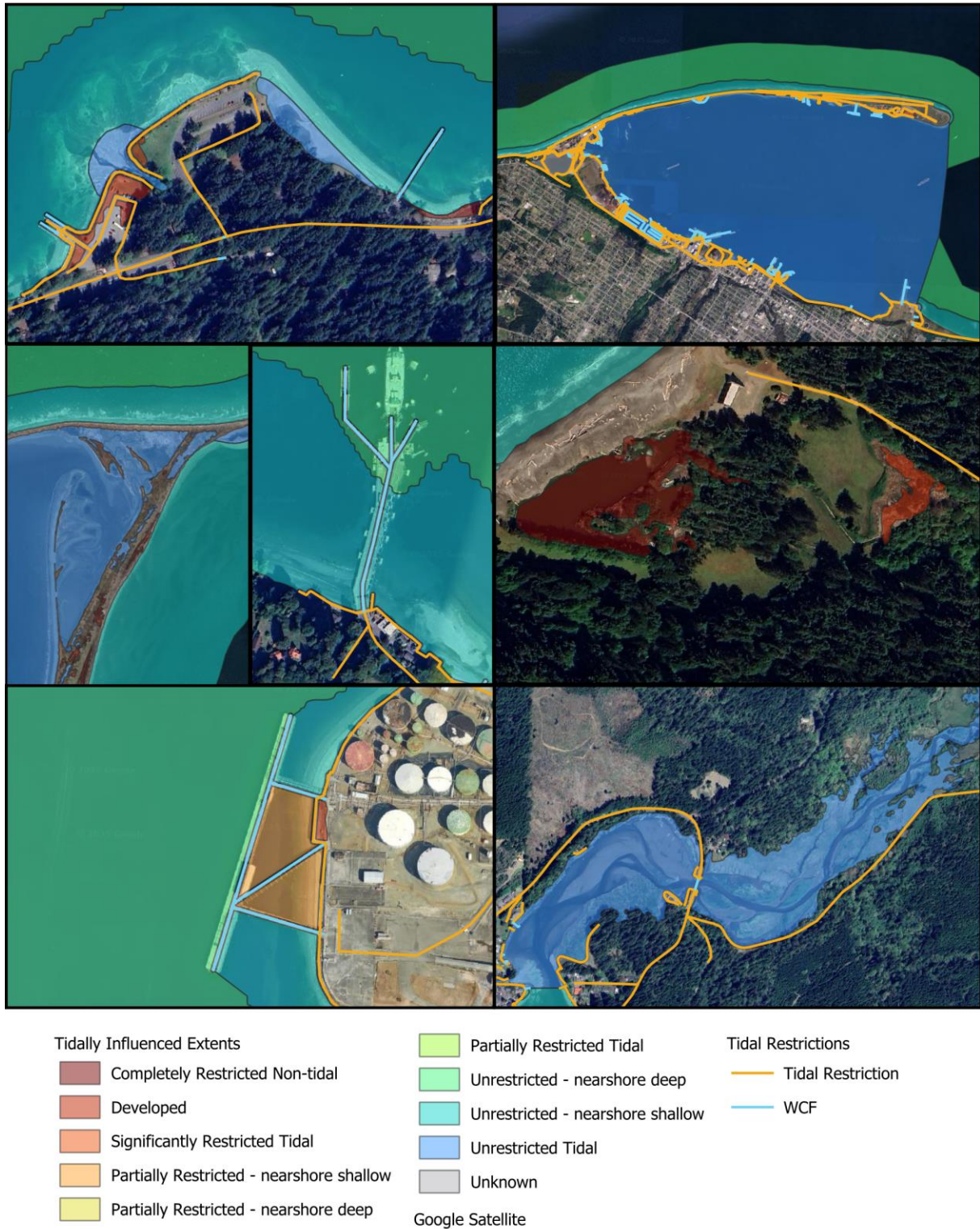


Figure 6. Example of tidally influenced extent categorized by landscape connectivity.

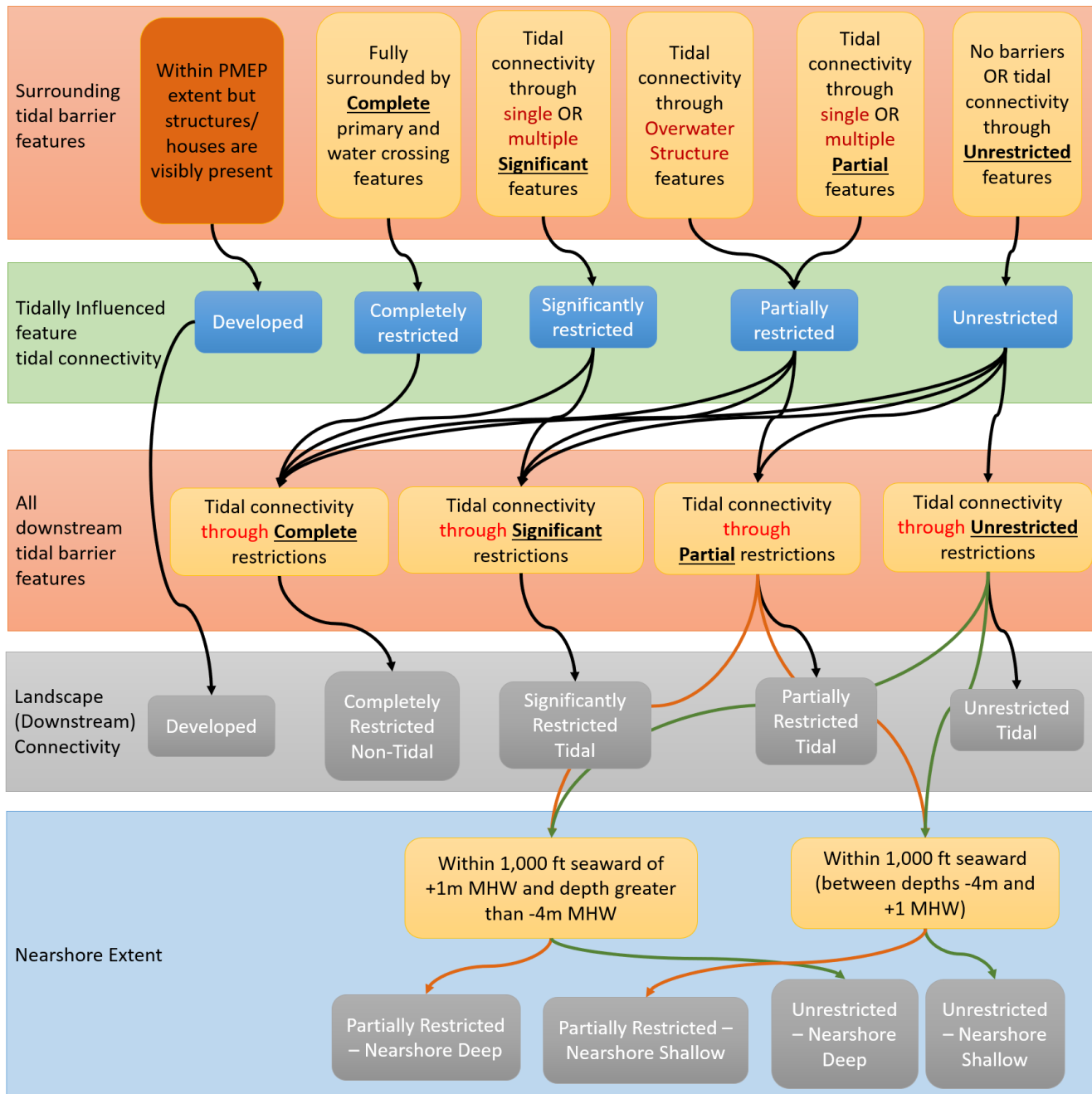


Figure 7. Flow chart for assessing the features' tidal connectivity and landscape tidal connectivity for tidally influenced extents.

Data review and validation

To facilitate the review, draft tidal restriction polyline and tidally influenced extent polygon data layers were uploaded to an ESRI ArcGIS web map hosted by WDFW. Reviewers were provided with a point data layer, where they were asked to add comments on restriction and tidally influenced features' existence, type, connectivity impacts, and fish passage. Regional experts from county, state, local, and federal agencies were identified using web searches and public communications and outreach, including the PSEMP Salmonid Workgroup, and we made direct requests to potential reviewers to review and provide feedback on tidal restriction and tidally influenced extent layers. To streamline the review process, reviewers were asked to examine features within their area of knowledge as opposed to all features within a given area. Unlike the large river delta mapping effort, we did not plan or conduct field validation for this phase. Comments received during the regional review were used to update feature attributes as appropriate, and the updates and source of information were recorded (see Appendix B: Mapping methods and data structure).

Compiling and sharing final spatial databases

This project produced the following spatial database products: (1) Original regional datasets compiled during data discovery with Unique IDs to link features to final data products; (2) Tidal restriction features (polylines) along the Puget Sound nearshore derived from regional data and remote sensing, with feature type and connectivity classifications; and (3) Tidally influenced (polygons) extents along the nearshore tidal habitats attributed by connectivity ratings from tidal restriction features. These spatial databases were published in ESRI ArcGIS Online compatible formats to support data use among a diverse audience, as well as a geodatabase platform, which supports point, polyline, and polygon features to organize, maintain, store, and develop project data. All spatial database products were published in the WA State Plane South NAD 83 HARN (EPSG 2927) coordinate reference system, the Washington State standard. Conformance with this standard will ensure consistency across the region and provide consistent reporting that can be used to develop and maintain a regional spatial database. These spatial databases will be available through [WDFW's ArcOnline](#) mapping application that will be available to the public, and links to the data are also provided through [PRISM](#) and [Salish Sea Restoration Platform](#).

RESULTS AND FINDINGS

Regional data synthesis

Thirty-six data portals were identified as potentially containing relevant data, of which 20 were used to download vector datasets (Appendix A: Data Discovery Log). Three other data portals were used to access reference raster and vector data. A total of 49 spatial datasets containing 267 vector layers were identified in data searches for the Large River Deltas and Puget Sound nearshore related to tidally influenced nearshore habitat and geomorphology, infrastructure and tidal restrictions, and hydrography (Appendix A: Data Discovery Log). Data coverage ranged from locally specific data sets (e.g., individual deltas, counties, or diking districts) to those with coverage for the West Coast of the United States, and included data sets with features describing tidal restriction, tidally influenced habitat, shoreline, floodplain, and channel features.

Tidal Restrictions

A total of 3,149 kilometers of tidal restriction features, including 363 kilometers of water crossing features, were digitized within the nearshore mapping extent (Table 6). Most of the tidal restriction features were composed of armor/fill (32%), roads (50%), docks/piers (10%), or railways (6%) with 4% of the total length of mapped features being classified as only water crossing features. Most of the tidal restriction features were classified as completely restricting tidal connectivity (86%) with an additional 10% classified as partial restrictions (Table 6). Approximately 1% of the tidal restriction features were classified as either significant restrictions or unrestricted features, while 2% were classified as having unknown connectivity (Table 6). Approximately 1% of the mapped features were classified as removed, abandoned, or breached, with a large majority (0.4%) classified as not restricting tidal connectivity (unrestricted). Some were classified as partially restricting tidal connectivity (0.09%) or significantly restricting tidal connectivity (0.18%), and completely restricted (0.27%). However, 0.42% of these removed features were classified as having unknown connectivity (Table 6). Approximately 1134 kilometers of dikes and levees, roads, unmapped roads, and railways were also classified as armored. Approximately 90% of the total length of mapped tidal restriction features were included in regional data sources, which translated to 316 kilometers of missing features that were identified and manually digitized using aerial imagery. Among the feature types, boat ramps, water crossing features associated with dikes and levees were the most common features manually digitized (missing from regional data).

based on the relative proportions of total mapped lengths (Table 6). An additional 0.12 kilometers of features were mapped based on regional reviewer comments.

Table 6. Length of tidal restriction features (kilometers) by feature type, source, and connectivity rating for Puget Sound (excluding large river deltas that were previously mapped). For length by source, regional data indicates that the feature was in regional datasets, while aerial imagery indicates the feature was not included in regional data and was manual digitized from aerial imagery. Regional reviewer indicates that the feature was mapped based on regional reviewer comments. WCF = water crossing feature.

Feature Type	Length by WCF		Length by Source			Length of feature by tidal connectivity rating					
	Primary Feature only	Primary Feature with WCF	Regional	Aerial	Reviewer	Completely Tidally Restricted	Partially Tidally Restricted	Significantly Tidally Restricted	Unknown Tidal Restriction	Unrestricted Tidal	Breached, Removed, Remnant/ Abandoned
Armor/Fill	1003.17	1.30	71.09	933.37	0.01	976.54	0.02	0.39	5.58	-	21.94
Boat ramp	23.68	-	15.79	7.89	-	16.01	-	-	7.45	-	0.22
Dike/Levee	22.16	0.59	9.37	13.38	-	12.44	-	0.01	2.01	-	8.28
Docks/Piers Isolated	-	323.27	21.73	301.53	-	0.90	318.68	-	0.26	1.44	1.99
WCF	-	11.46	1.43	9.90	0.12	0.37	3.28	0.61	0.35	3.99	2.86
Railways	200.11	2.21	9.07	193.25	-	200.33	0.37	0.64	0.07	0.91	-
Roads	1536.71	23.94	187.25	1373.39	-	1492.56	8.62	5.25	41.21	8.61	4.39
Total	2785.83	362.75	315.73	2832.72	0.13	2699.15	330.98	6.90	56.93	14.95	39.68

We also observed variation in the length and composition of tidal restriction features mapped among the Lead Entity areas in Puget Sound (Figure 8). We note that Nisqually consistently had the lowest amount of mapped tidal restriction features, but this was primarily due to most of the Lead Entity area being covered by the previous large river delta mapping effort. Among the Lead Entity areas, Hood Canal had the most length of mapped roads (324 kilometers), West Sound had the most length of armor (276 kilometers), WRIA 10/12 had the most length of railways (66 kilometers), Island Lead Entity had the most dike/levees mapped (8.5 kilometers), Hood Canal had the most boat ramps (7.2 kilometers), and West Sound had the most water crossing feature length (84 kilometers). Proportionally, most of the tidal restriction features were classified as completely restricting tidal connectivity among the Lead Entity areas (Figure 8).

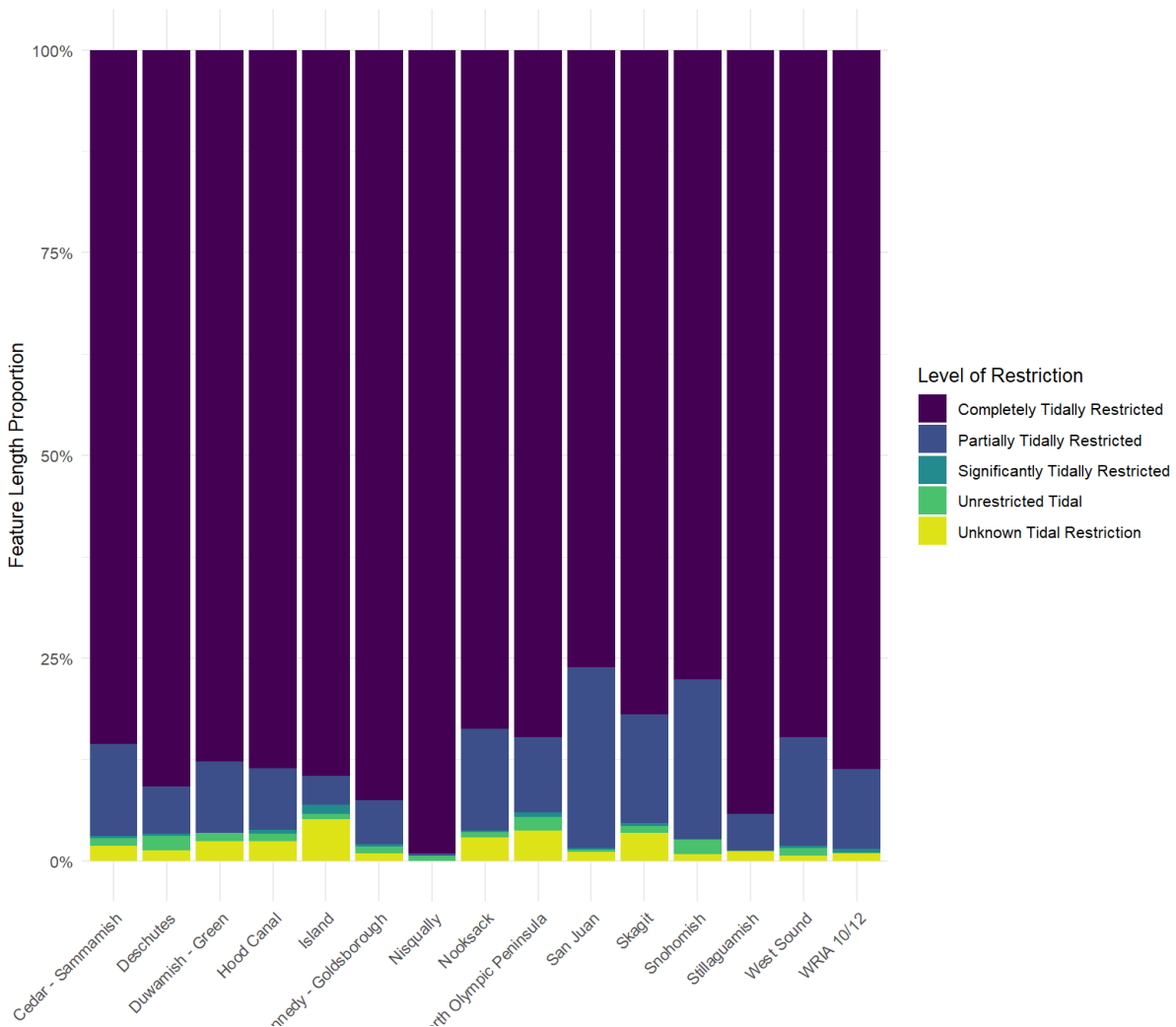


Figure 8. Proportion of tidal restriction features by tidal connectivity rating for each Lead Entity area (see Figure 3), excluding previously mapped large river deltas.

Tidally Influenced Extent

A total of 174,150 hectares of current and potential tidally influenced habitat were mapped and classified along the Puget Sound nearshore, not including areas within the previously mapped large river deltas (Hall et al. 2021). Nearshore deep and nearshore shallow polygons with partially restricted (influenced by docks and piers) and unrestricted ratings accounted for combined total of 161,470 hectares of the mapped polygon area (93%). Among the remaining 7% of mapped potential tidal extent landward of these nearshore shallow and nearshore deep habitats, 10,192 hectares were classified as unrestricted tidal habitat, 347 hectares as partially restricted tidal habitat, 211 hectares as significantly restricted tidal habitat, 1,438 hectares as completely restricted non-tidal habitat, 284 hectares as developed (non-tidal), and 209 hectares with unknown connectivity. This translates to a total of 10,750 hectares of current tidally influenced habitat extent (unrestricted tidal, partially restricted tidal, and significantly restricted tidal), and 1,646 hectares of potential habitat (completely restricted non-tidal and unknown tidal connectivity) within the potential tidally influenced habitat extent landward of the nearshore deep and shallow habitat polygons.

Among the Lead Entity areas, we also observed variation in the degree to which potential tidally influenced habitat extent was influenced by tidal restriction features (Figure 9). Overall, most of the tidally influenced habitat mapped from our tidal restriction features was classified as unrestricted tidally influenced habitat among the Lead Entity areas (Figure 9). However, Island, Pierce, and Stillaguamish were notable exceptions from the overall regional pattern with greater proportions of mapped habitat being classified with some degree of tidal restriction (Figure 9). Island Lead Entity area had the most completely restricted tidally influenced extents (993 ha) mapped while Kennedy-Goldsborough had the least (0.4 ha). West Sound had the most significantly restricted extent (61 ha) and Duwamish-Green had the least significantly restricted extent (0.5 ha). Nooksack had the most partially restricted tidal extent (131 ha) and Cedar-Sammamish had the least (0.4 ha). North Olympic Peninsula had the largest unrestricted tidal habitat extent (3,482 ha) and the Stillaguamish had the least unrestricted tidal habitat extent (2 ha). West Sound also had the most unknown connectivity habitat (61 ha), and Snohomish had the least (0.1 ha) classified as having unknown connectivity (Figure 9).

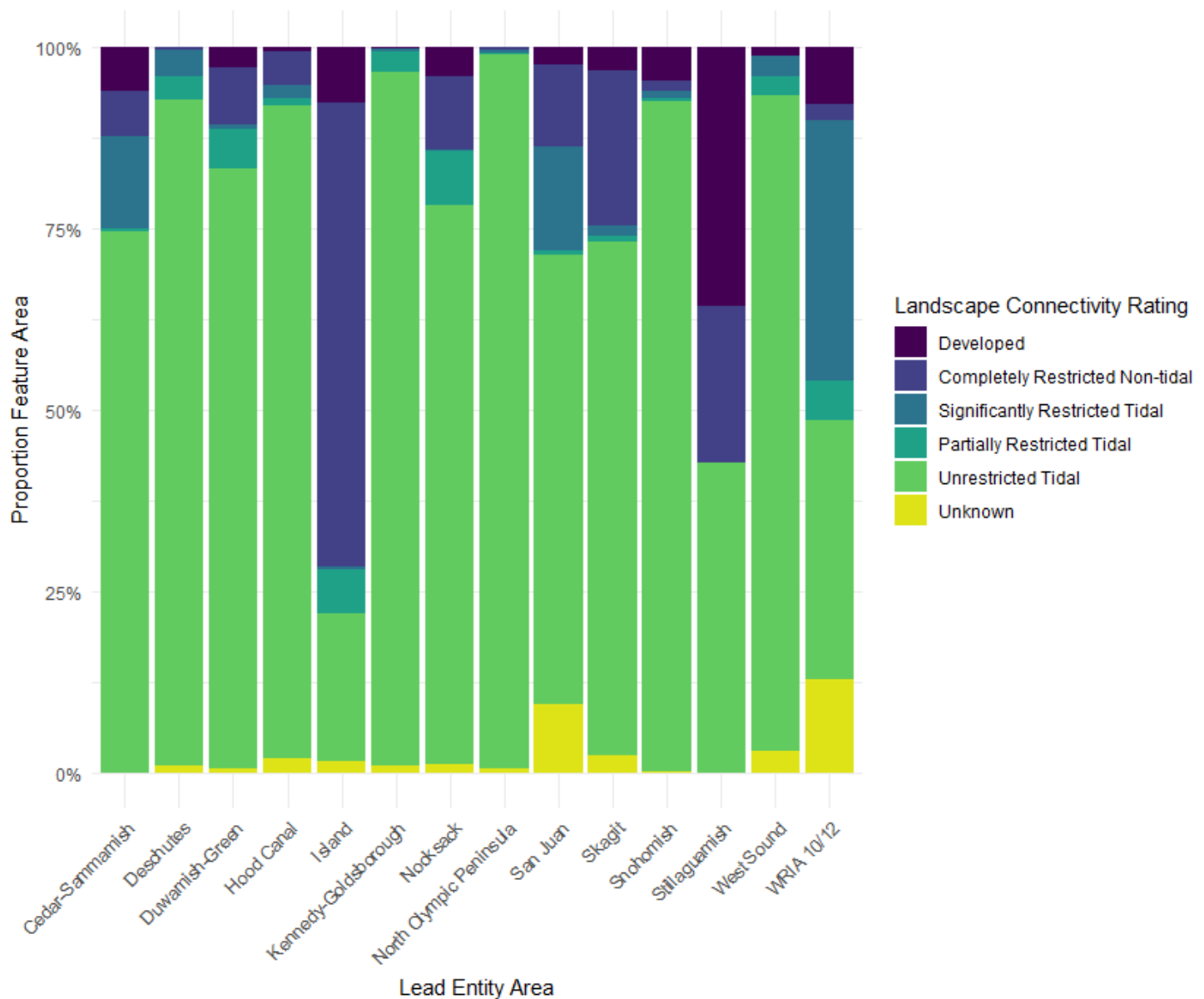


Figure 9. Proportion of area by landscape connectivity rating for each of the Lead Entity areas (see Figure 3). Nearshore deep and shallow were excluded to focus on potential tidally influence extent landward of the shoreline and within embayment features. The Nisqually Lead Entity Area was mapped completely in the Large River Deltas (ESRP Project #18-2250) and was not included.

Regional review

We received 97 comments from the Technical Advisory Group, project partners, and regional reviewers, with 41 comments about tidal restriction features, 35 regarding tidally influenced extent features, and 21 comments about removing features that did not exist or where duplicative of other comments.

Additionally, of the 97 comments, 30 comments were regarding both tidally influenced extent and restriction features that were within the mapping extent of the previously mapped large river dataset

(ESRP Project # 18-2250). Many of these comments were addressed in that project's regional review, but we archived additional comments for those data to be addressed in future updates.

Among the 41 comments regarding tidal restrictions, 22 comments identified features that were missing from our database, and this resulted in approximately 0.12 kilometers of tidal restriction features that were added based on regional reviewer comments. Fourteen comments confirmed our classifications, and therefore no changes were made, and three comments were about feature location being incorrect, resulting in those features being manually corrected. Two comments indicated that the feature had been updated (either added or removed) since the time of mapping due to restoration. For the feature that was added since time of mapping, we manually created a new tidally influenced extent polygon and the feature was created and the comment was retained in the review attribute section; previous classifications for connectivity and feature type were not filled out. For the feature that was removed since time of mapping, the connectivity impact was changed to unrestricted and the water crossing feature status was changed to removed. The previous connectivity rating and status were recorded. Among the 35 comments regarding tidally influenced extent features, 11 comments indicated that the feature was misclassified and these features were updated per reviewer comments. Two comments confirmed our classifications of tidally influenced extent, and one comment was regarding a feature that was added since time of mapping. For that comment, a new feature was created and the comment was retained in the review attribute section. Previous classifications for connectivity and feature type were not filled out. In total, 27 tidal restriction polyline features and 14 tidally influenced extent polygon features were updated or corrected in response to reviewer comments.

We also received a number of comments (21 comments) related to our initial attempts at classifying tidally influenced extent feature types by geomorphic or functional habitat types (e.g., barrier lagoons, closed lagoons, etc.). This revealed some confusion and inconsistency in our initial geomorphic feature type classifications. After consultation with our TAG and project partners, we decided to rely on our landscape connectivity classifications at this phase of the mapping. However, we did develop a preliminary classification system to consider in future application of these data (see Appendix E: Proposed Decision Tree for habitats). In addition, we retained segmentation of polygons at the mouth of embayment features to support continued development, refinement, and implementation of habitat classifications using the spatial data produced by this project.

DISCUSSION

Our remote sensing-based approach was a reasonably efficient and accurate method for creating an updated and consistent regional data layer of tidal restriction features and tidally influenced habitat extents for the Puget Sound nearshore. By leveraging existing regional data and synthesizing spatial information with aerial imagery and reference data layers, we were able to remove redundant features, correct alignment errors, update geometries to reflect current conditions, and map features originally missing from regional data. The spatial data produced by this effort in combination with the previously mapped large river deltas ([ESRP Project #18-2250](#)) represents the most up to date, complete, and consistent spatial datasets describing tidal restriction features, the extent of tidally influenced habitat, and the degree to which tidal connectivity is influenced by tidal restriction features for the Puget Sound region.

In total, we mapped 3,149 kilometers of tidal restriction features and 174,150 hectares of potential tidally influenced habitat using regional data and remote sensing for the Puget Sound nearshore. Most of the tidal restriction features mapped in this effort were in existing regional data sets, but approximately 18% were not previously included in regional data sources and were identified using aerial imagery or regional reviewer comments. Interestingly, the percentage of features that were mapped from aerial imagery and not in regional datasets for nearshore habitats was lower compared to the previous mapping effort for large river deltas (where about 46% of the features were missing from regional data) (Hall et al. 2021). While a large proportion of the features were already included in regional data, a significant part of our effort was consolidating and aligning features to match the aerial imagery. We manually adjusted the alignment for over 92% (2,902 kilometers) of the tidal restriction features in the database, which was largely focused on realigning armored banks, roads and unmapped roads, and delineating overwater structure features (e.g., docks and piers). This represents a significant improvement in the accuracy, completeness, and consistency of regional data describing tidal restriction features.

Most of the mapped tidal restriction features were classified as complete restrictions for tidal connectivity (86%), which was mostly related to the dominance of roads and railways among the primary feature types mapped along the nearshore. This was consistent with the findings of the large river delta mapping effort (Hall et al. 2021), although in contrast to delta habitats, we found that most restrictions ran parallel to the nearshore and PMEP extent and did not intersect or disconnect tidally influenced areas, but instead directly truncated the PMEP tidal extent. We initially focused our mapping

on all features with a 200-ft buffer of the PMEP or within the Beach Strategies NGF polygon, however, given the majority of this area was developed, we refined our mapping methods to focus on features directly interacting with or abutting the shoreline and PMEP extent, and major permanent infrastructure, such as roadways and railways, since these features would be important to consider when planning or identifying restoration opportunities. This was consistent with the delta methods, and helped to streamline mapping, given the extensive restriction features and development present along the nearshore.

While it is useful to understand the relative lengths of tidal restriction features by their connectivity impact ratings, this does not directly translate to the degree to which tidal connectivity is restricted with respect to the potential extent of tidally influenced area. To do this, we used our mapped tidal restriction features to “carve up” the potential extent of tidal influence from the PMEP extent, and attribute these polygons with connectivity ratings from our tidal restriction features. In doing this, we found that most of the extent of potential tidal influence along the nearshore was classified as unrestricted tidal habitat (80%, excluding nearshore deep and shallow habitat extents). Similar to the tidal restrictions, this also contrasts with the findings of our previous mapping efforts in the large river deltas where most of the habitat was classified as having some degree of tidal restriction (partial, significant, or completely restricted) (Hall et al. 2021). Among the 20% of the mapped tidally influenced habitat landward of the nearshore shallow and deep polygon extents, partially restricted tidal habitat accounted for 3%, significantly restricted tidal, developed, and unknown connectivity habitat each accounted for 2% of the mapped extent, and 11% was classified as completely restricted non-tidal habitat.

The areas classified as completely restricted non-tidal habitat represent potential tidally influenced habitat that could be the focus of restoration or recovery planning. However, it is important to note that the PMEP extent used as our basis of mapping represents the modelled maximum extent of tidal flooding based on current topography and extreme tidal water levels (PMEP 2018; Brophy et al. 2019). Therefore, what we describe as potential tidally influenced habitat extent (completely restricted non-tidal), does not represent historical extent given that elevation models were derived from modern datasets and already integrate some degree of fill and development in the landscape. In addition, we noted that there was little difference between what we classified as feature connectivity (based on the tidal restriction features that immediately surround a polygon) and landscape connectivity (net tidal connectivity to a polygon considering all downstream or seaward features). This contrasts with the large

river delta habitat mapping effort (Hall et al. 2021), and may be due to the comparatively infrequent direct intersection of tidal restriction features and potential tidal influence extent along the nearshore. Therefore, we recommend that practitioners primarily use landscape connectivity ratings when evaluating the extent of tidally influenced habitats and the degree to which they are impact by tidal restrictions given that the landscape connectivity rating accounts for the potential impacts of downstream tidal restriction features. However, we included both feature and landscape connectivity ratings in the dataset to support other uses where information on the effects of tidal restrictions immediately surrounding a polygon are desired.

Given that the data produced by this effort are intended to support regional salmon recovery planning and habitat status and trends monitoring programs (like [PSP Vital Sign Indicators and Salmon Habitat Indicators program](#)), we also summarized regional patterns among Lead Entity (LE) areas. LE areas are similar to Puget Sound sub-basins and counties but are grouped by stocks within a watershed, and are managed by a Lead Entity group for salmon recovery plans in Washington state. However, these LE areas can also be generally viewed as geographical areas to other agencies and comanagers, and the spatial nature of the data facilitates summarizing using any geographical boundaries (e.g., watersheds, counties, marine basins, etc.). As expected given regional gradients in land use within the region, we observed variation in the lengths of tidal restriction features and degree to which tidally influenced extents were impacted by tidal restriction features among Lead Entity areas. This was consistent with the previous large river delta mapping effort (Hall et al. 2021) and is reflective of gradients in the degree to which land use and development have impacted the landscape at a regional scale. From this effort, we note that the Island Lead Entity area had the most completely restricted tidally influenced extents (993 ha) while Kennedy-Goldsborough had the least (0.4 ha). North Olympic Peninsula had the most unrestricted tidal habitat (3,482 ha) and the Stillaguamish had the least unrestricted habitat (2 ha). West Sound had the most restrictions mapped (649 kilometers), of which most were complete restrictions (550 kilometers). The Stillaguamish Lead Entity area had the least length of tidal restriction features mapped among the Lead Entity areas (9.5 kilometers). These comparisons exclude the Nisqually Lead Entity area given that nearly the entire area was mapped during the large river delta mapping phase (Hall et al. 2021). We provide detailed tabular summaries for each Lead Entity area to support regional salmon recovery planning and habitat status and trends monitoring programs in Appendix C: Results.

Applications and next steps

In combination with our previous mapping efforts for Puget Sound's large river deltas (Hall et al. 2021), completion of this phase of mapping has created the most complete, consistent, and up to date spatial database of tidal restriction features and tidally influenced habitat for the Puget Sound region. These datasets directly addressed a significant regional data gap by providing consistent regional scale data that can be used to inform Puget Sound salmon recovery planning and evaluation in several key ways that include: (1) habitat status and trends monitoring and evaluation, (2) refining and reporting on recovery targets and progress towards recovery, and (3) identification and prioritization of restoration opportunities.

Habitat status and trends monitoring and evaluation: The extent of tidally connected habitats has been identified as a limiting factor for Puget Sound Chinook populations, and regional recovery strategies have identified restoration of tidal connectivity as a priority for the recovery of Chinook in the Puget Sound region (Beamer et al., 2005; PSP 2016; Beechie et al. 2017). Tracking the status and trends of tidally influenced and estuarine habitat extent is an important component of recovery planning and evaluation (Beechie et al. 2017). Regionally consistent spatial datasets that can be regularly updated are key to habitat status and trends monitoring and evaluation, and our spatial database framework provides the first step towards this. With completion of mapping for nearshore habitats and previously completed large river delta habitats, our spatial database provides consistent spatial data that can be used to describe the extent and composition of tidal restriction features and the extent of tidally influenced habitats and the degree to which tidal connectivity is impaired at a regional scale circa 2017-2022. The large river delta datasets have already been used to update reporting on habitat status and trends indicators for important regional recovery planning and evaluation programs including: Puget Sound Partnership (PSP) Vital Sign (VS) and Salmon Habitat Indicators (SHI) (Ramirez, 2019a, b; PSP et al. 2022), National Oceanic and Atmospheric Administration's (NOAA) Salmon Habitat Status and Trends Monitoring Program (SHSTMP) (SHSTMP 2018), and Puget Sound Ecosystem Monitoring Program (PSEMP) Spatial Data Work Group (SDWG) (PSEMP 2022), and we anticipate that these new data that complete data coverage at the Puget Sound scale will be used in the same way.

With the completion of this nearshore mapping effort, spatial data are now available to support habitat status and trends monitoring and reporting for nearshore habitats that can provide important non-natal rearing and refuge habitats for juvenile Chinook Salmon (e.g., pocket estuaries, lagoons, embayments, and other tidally influenced wetland and channel habitats) (Beamer et al., 2005). In fact, the [PSP Vital](#)

[Sign and Salmon Habitat Indicators program](#) has been working towards refining and updating habitat status and trends indicators and reporting for these habitats (area and count of accessible pocket estuary and embayments habitat). The data produced from this mapping effort will directly inform the refinement of those indicators in coordination with another ongoing Estuary and Salmon Restoration Program Learning Project (Embayment Strategies for Restoration and Protection [PRISM #22-1767](#)). Although we initially attempted to classify polygons into functional or geomorphic habitat types, more work is needed to develop a regionally consistent habitat classification system that is useful for recovery planning and evaluation. To help with this, we have developed a preliminary habitat classification tree (see Appendix E: Proposed Decision Tree for habitats) to support development of a regionally consistent classification of the tidally influenced polygons mapped by this project to support habitat status and trends monitoring and reporting for nearshore habitats important to salmon recovery.

The ability to update the spatial database and track changes over time are also key to habitat status and trends monitoring and reporting. The spatial database we developed includes fields to track changes in both tidal restriction and tidally influenced extent features. For example, status and modification fields allow the database to be updated when features are removed, breached, or modified through restoration actions or natural change while retaining information on the previous feature type and geometry of the features within the database (see Appendix B: Mapping methods and data structure). These fields can also be used to update and track changes to the data as additional regional reviews or comments are received, which we recommend continued regional review given that there are many features still flagged as unknown or with low certainty. In both cases, guidelines will be developed in coordination with the Puget Sound Partnership to maintain and update the database to support use of these datasets for regional habitat status and trends monitoring and reporting. However, we do note that landscape connectivity ratings have been manually attributed and are not dynamically enforced with networking at this time, and therefore updates to connectivity ratings will need to be manually updated (for both the feature directly changed and any associated features landward of that feature) as the database is maintained in the future.

Refining and reporting on recovery targets and progress towards recovery: As noted above, these datasets provide regionally consistent spatial data needed to report on indicators of habitat status and trends. By integrating tidal connectivity ratings into our dataset, these data allow for habitat to be quantified with respect to varying degrees of tidal connectivity. We have already seen updates to the

PSP VS and SHI reporting protocols to include reporting by tidal connectivity rating rather than just accessible area based on our previous efforts in the large river deltas (Ramirez, 2019a, b; PSP et al. 2022), and this provides more information to inform recovery targets and evaluation of progress towards recovery. We envision the same approach being adopted for developing, refining, and reporting on the PSP's VS and SHI nearshore embayment and habitat indicators (e.g., area and count of accessible pocket estuary and embayments habitat). Similar to our recommendations for the large river deltas, we also recommend that recovery targets for nearshore embayment and pocket estuary habitats be developed at watershed or Lead Entity area scales. This allows recovery planning to account for relative degree to which embayment or pocket estuary habitats are currently available, the degree to which those are impaired with respect to tidal connectivity, and potential tidally influenced habitat – which varies among the Lead Entity areas due to natural variations in geomorphology as well as land use history.

Identification and prioritization of restoration opportunities: The spatial nature of our database allows practitioners and stakeholders to query tidal restriction polyline or tidally influenced extent features by feature types, connectivity ratings, shoreform, or geographic area (e.g., Lead Entity area). Furthermore, polygon features that describe the extent of tidally influenced habitats or potential extent are also linked to the associated tidal restriction features that surround the polygon feature. This allows the user to identify a potential restoration site (e.g., culvert removal replaced with a bridge or removing armored features, etc.) and the features that impact tidal connectivity to specific polygons to inform restoration planning. To demonstrate the application of the spatial database for the identification and prioritization of restoration opportunities, consider a hypothetical example of a practitioner that seeks to identify and prioritize opportunities to increase the amount of tidally influenced habitat by restoring tidal connectivity to areas that are currently completely disconnected. In this case, the practitioner can use the spatial database to select geographic areas of interest (if desired), and then query the polygon dataset to select features that are classified as Completely Restricted Non-Tidal habitat. These features represent areas that are within an appropriate elevation to be tidally influenced but are currently completely disconnected from tidal flooding due to tidal restriction features or natural topography. The selected features can then be filtered or prioritized using information within the database (e.g., shoreform or surrounding tidal restriction feature types) or by joining with other datasets (e.g., parcel data to provide ownership information, accessibility via roads or other transportation infrastructure). For example, the practitioner may want to filter or prioritize the selected polygons to those that are within publicly held lands, with the assumption that those sites would be easier to restore. Additionally, the practitioner may

want to filter or prioritize by the types of tidal restriction features that are associated with the polygons. For example, addressing tidal connectivity at already existing water crossing features that completely restrict tidal connectivity (e.g., traditional flap gate or floodgates) through restoration or enhancement actions may be easier or lower cost than sites that would require extensive excavation or channel construction to restore or enhance tidal connectivity to a site. In this way, the practitioner can use the spatial data to identify and prioritize restoration opportunities to address specific objectives (in this case, increasing the amount of tidally connected habitat). Another example could be using the spatial data to summarize by drift cell types to support the identification and prioritization of restoration opportunities from a drift cell perspective (e.g., understanding possible co-benefits of restoring both tidal connectivity and sediment supply or evaluating opportunities for restoration of tidal restrictions at the drift cell scale). To support the identification and prioritization of restoration planning, we envision working with ESRP and PSP to develop widgets and tools for the online map hosted by WDFW.

Opportunities for updating related organizational data to align recovery efforts: In addition, our spatial data provides information on water crossing features that can directly inform updating regional databases such as the Washington Department of Fish and Wildlife (WDFW) Fish Passage and Diversion Screening Inventory (FPDSI) database (WDFW 2020). The WDFW FPDSI represents a significant regional resource for identifying and funding restoration opportunities to improve fish passage and access to habitats. Inventories and evaluations of fish passage at WCFs in tidally influenced habitats has been a critical data gap in the FPDSI. Our database identifies numerous WCF in tidally influenced areas previously not included in regional data, including the FPDSI database, which can be used to significantly improve the completeness of the regional inventory. Therefore, these data can be used to inform future assessments to evaluate and restore fish passage issues associated with water crossing features in tidally influenced habitats by providing an updated spatial inventory of potential features to evaluate (WDFW 2019a, b).

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APPENDIX A: DATA DISCOVERY LOG

Table A.7. Web data portals examined to identify available datasets for the large river delta and nearshore tidal restriction and habitat features. This is not a complete list of data sources as other data were directly downloaded from regional data stewards. Hyperlinks to the web portals are shown in blue and bold. Downloaded refers to if data were downloaded and used from the portal. NA means the data were unavailable.

Source	Date accessed	Data coverage	Spatial coverage	Time Periods	Downloaded?
UW Washington State - GIS Data	12/20/2020	Spatial data from comprehensive change analysis for Puget Sound, restrictions, habitat, and shoreline features.	All of Puget Sound by major basins	Historic & current	YES
Geomorphological Research Group	3/5/2019	Major local data projects and locally hosted GIS data, raster, and vector datasets	PNW, Washington, and Puget Sound	Historic	NO
WDFW PHS	3/5/2019	Link semi-broken, WDFW website updated, and no GIS data downloads were located	NA	NA	NO
WDFW Maps and Data	12/20/2020	Fish passage barriers, WDFW data sets	Washington State	Current	YES
USGS EROS	3/5/2019	State and national datasets	Washington State	Current	YES
StreamNet	3/5/2019	Watershed boundaries, fish distributions	Washington State	Current	NO
USGS NHD	12/20/2020	Elevation DEMs, flow courses, watershed boundaries	Washington State	Current	NO
UW School of Oceanography	3/5/2019	Bathymetry and topography for Puget Sound, PRISM data (waves, sediment, and other nearshore data)	Washington State	2000 & 2005	NO
USGS Coastal and Marine Geology Program	3/5/2019	Interactive maps of marine data	Puget Sound, Incomplete, Offshore	Current	NO
Puget Sound LiDAR Consortium	3/5/2019	LiDAR Data	Puget Sound, Incomplete	Current and archived	YES – Reference data
UW Washington State – Aerial Imagery Data	12/20/2020	Aerial imagery (4-band, NAIP, Quads, Orthos)	Washington State	Archived & current	YES - Reference data
Whatcom County	6/18/2019	County boundary, Washington WRIA boundaries, NRCA Conservation, species habitats, infrastructure	Whatcom County	Archived data	NO
Skagit County	12/20/2020	Hydrology control structures, roads	Skagit County	Current	YES

Source	Date accessed	Data coverage	Spatial coverage	Time Periods	Downloaded?
Snohomish County	6/19/2019	Waterbodies, parcels, drainage networks, levees, districts	Snohomish County	Current	YES
King County	6/19/2019	Levees, revetments, seawalls	King County	Current	YES
Pierce County	6/20/2019	Levees, revetments	Pierce County	Current	YES
Kitsap County	6/20/2019	Districts and boundaries, natural features	Kitsap County	Current	NO
Jefferson County	6/20/2019	Roads, CMZs, habitat	Jefferson County	Current	YES
Clallam County	6/20/2019	Roads, streams	Clallam County	Current	YES
San Juan County	6/20/2019	Roads, parcels, habitat	San Juan County	Current	YES
Island County	6/20/2019	Roads, culverts, streams, parcels, diking districts	Island County	Current	YES
WSDOT	12/20/2020	Fish passage barriers	Washington State	Current	YES
WA DOE	12/20/2020	Levee inventory, beach access points and types	Washington State	Current	YES
WA DNR	12/20/2020	Watercourses, shore zones, shoreline modifications, DNR roads	Washington State	1994-2000	YES
Seattle GeoData	12/5/2019	Drainage and wastewater lines, culverts and ditches, storm outfalls, swales	City of Seattle	Current	YES
SoundIQ	12/5/2019	PDF maps of shoreline characteristics, including beaches, biological features, and developments	Puget Sound, Strait of Juan De Fuca	Current	NO
Washington State Coastal Atlas Map	12/5/2019	Shoreline modifications and shoreline armoring	Washington State	Current	NO
Point No Point Treaty Council Historical Nearshore	12/5/2019	Shoreline alterations, current day habitat delineations	West Puget Sound, Strait of Juan de Fuca	Historic	YES
US Fish and Wildlife Service NWI	12/5/2019	National Wetlands Inventory	Washington State	Current	YES - Reference data

Table A.8. Datasets used in the tidal restriction mapping project. Dataset names, the number of layers, a data description, spatial coverage and reported years of data collection are all included. This table is not complete and new datasets will be added as they are delivered. A (-) refers to unknown.

Dataset name	# of layers	Data included	Spatial coverage	Year	Source
Beach Strategies	4	Shoretype, armored shoreline, drift cells, land use	Puget Sound	2017	Coastal Geologic Services
Beamer Pocket estuaries	3	Pocket estuary locations and habitat maps	San Juan County	2014, 2018	Eric Beamer
CFS-PSP Pocket Estuaries	2	Point locations of pocket estuaries and small river deltas	Puget Sound	2019	Puget Sound Partnership, Cramer Fish Sciences
Clallam County Roads	1	Clallam County roads	Clallam County	2008-2018	Clallam County
Clallam County Streams	1	Clallam County streams	Clallam County	1992-2010	Clallam County
Estuaries Common Indicator	1	Estuary habitat coverage	Puget Sound, Strait of Juan de Fuca	2019	Puget Sound Partnership
Estuaries Vital Sign Indicator	1	Restoration efforts	Puget Sound, Strait of Juan de Fuca	2006-2018	Puget Sound Partnership
Fish Passage Barrier and Diversion Screening Inventory	3	Fish passage barrier inventory that includes water crossings, culverts, tide gates, and bridges	Washington State	1985-2017	WA Dept. of Fish and Wildlife
Hood Canal Coordinating Council	4	Restoration and armoring	Hood Canal	Multiple years	Hood Canal Coordinating Council
Island County Culverts	1	Culvert data for Island County	Island County	2015-2018	Island County
Jefferson County Road Centerline	1	Jefferson County roads	Jefferson County	2017-2018	Jefferson County
King County Bridges and Roads	2	Bridges and roads maintained by King County	King County	2018-2019	King County
King County Levees and Revetments	1	King County levees and revetments	King County	2019	King County
King County Seawalls	1	Seawall maintained by King County Roads Division seawall line	King County	1990-2018	King County
Lower Duwamish Inventory	7	Shoreline armoring, hand launches, outfalls, overwater structures, pilings	Duwamish River	2004	King County
Nisqually Indian Tribe Estuary Restoration	2	Shoreline modifications and updated levees and dikes	Nisqually Delta	2013	Nisqually Indian Tribe

Dataset name	# of layers	Data included	Spatial coverage	Year	Source
NOAA Continually Updated Shoreline Product (CUSP)	1	NOAA shoreline delineations from LiDAR and national shoreline products	West Coast, USA	1992-2018	NOAA
NOAA Habitat Features and Restored Areas	5	Tidal habitats feature types and tidal restoration projects	Puget Sound	2010-2020	NOAA
NWFSC Tide Gate Survey	1	Survey of a specific tide gates in the Pacific Northwest	Washington and Oregon	2011	NOAA Northwest Fisheries Science Center
Pierce County Levees and Revetments	1	Pierce County levees and revetments	Pierce County	1998	Pierce County
PMEP Estuarine Biotic Habitat	1	Wetland habitat for tidal wetlands	West Coast, USA	2020	NOAA Pacific Marine and Estuary Fish Habitat Partnership
PMEP Tidal Wetland Loss	2	Polygons of current (from NWI current tidal wetlands) and lost (historic) tidal wetlands (from PMEP West Coast Estuary Extent)	West Coast, USA	2020	NOAA Pacific Marine and Estuary Fish Habitat Partnership
PMEP West Coast Estuary Extent	2	Published (2018) and draft (2022) maps of potential tidal wetland extent based on elevation and tidal exceedance.	West Coast, USA	2018, 2022	NOAA Pacific Marine and Estuary Fish Habitat Partnership
Point No Point Treaty Council Historical Nearshore	11	Shoreline alterations; current day habitat delineations	West Puget Sound, Strait of Juan de Fuca	2003, 2006	Point No Point Treaty Council
PSNERP Change Analysis	112	Delta features including stream crossings, fish passage barriers, tidal barriers, and current and historic wetland habitat extents	Puget Sound, Strait of Juan de Fuca	1850-1890; 2000-2006	Puget Sound Nearshore Ecosystem Restoration Project
PSP Input Data	4	Dikes, levees, and roads used to support the PSP floodplain analysis	Washington state	2019	Puget Sound Partnership (compilation of Northwestern Indian Fisheries Commission and local county data)
PSP Levees of Puget Sound	1	Inventory of PS levees compiled and standardized	Puget Sound	2023	ESA, Puget Sound Partnership
PSP NWIFC Levee Inventory	19	Statewide levee dataset under development through NWIFC and PSP	Puget Sound, Strait of Juan de Fuca	2017	Puget Sound Partnership (compilation of Northwestern Indian Fisheries Commission and local county data)
San Juan PIAT	2	Shoreline data attributed with habitat, shoreline modifications, and geomorphology	San Juan County	2012	Friends of the San Juans

Dataset name	# of layers	Data included	Spatial coverage	Year	Source
San Juan Road Centerlines	1	San Juan Roads	San Juan County	-	San Juan County
Seattle GeoData	5	Drainage and wastewater lines, culverts and ditches, storm outfalls, swales	City of Seattle	2019	City of Seattle, Seattle Public Utilities
SSHIAP Shoreline	2	Shoreline data attributed by shoreline type for the Washington Coast and Puget Sound	Washington	2009	NWIFC
SHSTMP Datasets	3	Large river delta areas and delta habitat features; over water structures	Puget Sound	2013-2016	NOAA Northwest Fisheries Science Center Salmon Habitat Status and Trends Monitoring
Skagit County Hydro Flow Control Structures	1	Flow control structure inventory that includes tide gates, pump stations, and floodgates	Skagit County	2007	Skagit County
Snohomish County Bank Condition Survey	1	Field surveys of bank conditions that includes levees, dikes, revetments, and bulkheads	Snohomish County	2002-2006	Snohomish County
Snohomish County Drainage Inventory	3	Flood assets including flap gates, flood control embankments (levees), and pump stations	Snohomish County	2017-2018	Snohomish County
Snohomish County Surface Water Management Inventory	17	Comprehensive drainage inventory	Snohomish County	1995-2018	Snohomish County
Snohomish County Waterbodies	1	Snohomish County streams, rivers, habitat, lakes	Snohomish County	2009	Snohomish County
SRSC Delta Data	8	Tidal delta area, habitat, and type; fish paths	Skagit River	2000, 2004, 2013, 2019	Skagit River System Cooperative
TRAN Washington State Shape	8	Federal Railroad Administration rail lines; public and private airports and runways; street segments; trail systems	Washington State	2019	USGS
USACE National Levee Database	8	National levee database: crossings, point long profiles, protection area polygons, pump stations	Washington State	2019	United States Army Corps of Engineers
WADNR Shoreline Modifications	1	Inventory of shoreline modifications	Washington State coast	1994-2000	WA Dept. of Natural Resources
WADNR State Roads	1	DNR proprietary roads	Washington State	2017-2019	WA Dept. of Natural Resources
WADOE SEA OCN Public Beach Access	2	Public beach access, area, and type	Washington State coast	2009-2010	WA Dept. of Ecology
WADOE SEA WAT Levee Inventory	1	Washington state levee and material	Washington State	1987-2010	WA Dept. of Ecology

Dataset name	# of layers	Data included	Spatial coverage	Year	Source
WAECY Levee Inventory	1	Synthesis of levees from USACOE, FEMA, and local levee managers including land use, vegetation, and salmon habitat metrics	Washington State	2016	WA Dept. of Ecology
WDFW High Resolution Land Cover	1	High resolution land cover data	Washington State	2006-2017	WA Dept. of Fish and Wildlife
Whatcom County Floodgate Survey	1	Nooksack River and floodplain floodgates	Nooksack River	2017	Whatcom County
WSDOT Fish Passage Inventory	4	Fish passage barrier descriptions and statuses	Washington State	2018	WA State Dept. of Transportation

APPENDIX B: MAPPING METHODS AND DATA STRUCTURE

Tidal restriction regional data processing and mapping

The processing software QGIS (QGIS 2024) was used to visualize and process all datasets. An original copy of all datasets was retained and a working version of each of the datasets was projected to the project coordinate reference system (CRS), WA State Plane South NAD 83 HARN (EPSG 2927) and saved as a geopackage (a QGIS layer package that allows for storage of large datasets of multiple geometries and data types). To maximize storage and usability, the projected datasets were clipped to a 656 ft (200 m) buffer of the shoreline study area and the fix geometry tool was used to address potential errors generated from the projecting and clipping process.

Many of the original data sources contain detailed information that may be useful for some applications but weren't included in the streamlined database structure. Therefore, we performed the same process used in the mapping of large river delta tidal restrictions and delta tidal wetlands and created a Unique ID for all features contained in the original data sources by combining the original dataset name and row number. This allows the use of the Unique ID to link the features to their original data source by using a join operation in GIS (Table B.10).

All projected, clipped, and Unique ID attributed datasets were then loaded into a QGIS project with aerial imagery and other reference data sources for use in mapping tidal restriction and polygon features.

The regional data review and remote sensing protocol included several steps that are described in the following sections:

- (1) synthesis of redundant features and correcting spatial alignment,
- (2) updating removed or modified features,
- (3) digitizing missing features,
- (4) classification of feature types and certainty, and
- (5) classification of feature tidal connectivity and certainty.

(1) Synthesis of redundant features

Regional data varied in their geometry (lines versus points) used to depict tidal restrictions (e.g., culverts, levees, bridges) as well as their spatial resolution and accuracy. In addition, many features were

captured or described by multiple data layers that had differing alignments within small spatial scales, creating problems for regional scale analysis and selection of appropriate data layers. Such variations in regional data are shown in Figure B.10 to illustrate our remote sensing approach to synthesizing and updating regional data layers into a consistent spatial database. We reviewed redundancies (i.e., the same physical feature included in multiple datasets) and gave precedence to; (1) local datasets over regional data (e.g., county vs state datasets) and (2) datasets with higher spatial accuracy relative to aerial imagery. All qualifying features from the regional data were copied into the CFS tidal restriction data geopackage layer, and their source was retained in the feature Unique ID.

(2) Digitizing missing features

Visible features not included in the regional datasets were digitized at a scale of 1:1,000 and the source was recorded as aerial imagery to indicate the feature was digitized from remote sensing. Placement of features was based on aerial imagery, but supplemental data (e.g., USGS 3DEP hill-shaded DEM, PMEP tidal exceedance polygons, LiDAR, or oblique shoreline imagery) were used where available to inform placement where features were obscured by cover or shadows or couldn't otherwise be seen in the aerial imagery. Features were also given a certainty rating for presence; features not clearly visible in the imagery were flagged as low certainty and for further evaluation in the field or in regional review (Table B.10).

(3) Correcting alignments and updating features

We modified regional data features as needed to align them to the feature center point as visible in the aerial imagery. All manual feature corrections were performed at a scale of 1:1,000, and corrections were recorded for each feature to indicate the type of correction. Figure B.10 shows an example of the synthesized and corrected regional data layer outputs from the compiled regional data. Features were also attributed with status as “Present,” “Breached,” or “Removed,” if indicated in the regional data, or if observed in the aerial imagery (Table B.9). If a feature was mapped as present in the regional data, but was observed to have been removed, breached, or modified in the aerial imagery, the feature alignment was maintained and the previous feature type and connectivity was noted, but the feature type, connectivity, and status were updated to reflect the imagery. Restoration efforts were incorporated into the tidal restrictions database when documented in the regional data or visible in the aerial imagery.

(4) Classifying feature types and certainty

Features were classified using a two-tiered nested structure that included attributing a primary and water crossing feature type (where applicable), which are defined and described in detail in Table 2. Feature types were identified using regional data or aerial imagery. The first tier described the primary feature type and included roads and railways, dikes and levees, armored or filled banks, boat ramps, and footpaths if applicable.

The second tier described the water crossing structure type, if applicable. Water crossings included bridges, causeways, piers, and docks, floodgates and pumpstations, self-regulating tide gates, culverts, pipes, open crossings (e.g., breaches or removed features), unknown, or NULL if no water crossing feature was associated with a primary feature (Table 2). Water crossings not mapped in the regional data were identified in the aerial imagery by the evidence of flow or tidal connectivity under a solid feature. If the water crossing was not part of a primary feature (e.g., agricultural bridges and culverts without a graded road), then the primary feature was classified as NULL. If a water crossing existed as part of a primary feature, the primary feature line was segmented on either side of the crossing (using the mapped regional data location and aerial imagery as reference), and the segment was classified by both the primary feature (e.g., roads, railways, dikes, levees, armored banks) and the water crossing feature type (e.g., floodgates, self-regulating tide gates (SRTs), culverts, bridges and causeways). Water crossing features that were included in the WDFW FPDSI database (WDFW 2020) were also attributed with fish passage status information and the unique site ID (reflective of information available on Date). All tidal restriction features were also classified as high or low certainty for the feature type classification, based on if the feature type was listed in the regional data or clearly visible in the imagery (high) or if the feature type was determined from the imagery (low). Additionally, many armored banks were mapped in the regional data as adjacent to roads and railways running along the shoreline, however these are essentially a single feature, the road or railway with armor to protect it (Figure B.10). To account for these features, we added an additional attribute of “Armored,” so features adjacent to the shoreline could be mapped as a single feature of their primary type (for example, railway) with armoring, as opposed to two separate features (one line for the railway, one line for the armor).

We also documented overall location data for restriction features by adding attributes for the Chinook Recovery Watershed, the study extent strata the feature is located in (e.g., seaward of the Beach Strategies NGF, within the Beach Strategies NGF 0-200 ft polygon, within the PMEP extent or mapped tidal wetland extent, and/or within the 200 ft buffer), and the Beach Strategies NGF shoreform (CGS

2017). This will allow compatibility and comparison with other nearshore programs that utilize the Beach Strategies data.

(5) Classification of feature tidal connectivity and certainty

Tidal connectivity was classified based on a combination of feature type information, interpretation of aerial imagery, and supplemental data sources. Given that aerial imagery interpretation limited our ability to classify tidal connectivity, we used general categorical classifications of tidal connectivity impacts based on the feature type. These classifications were based on the approach used in the lower Columbia River estuary for mapping and classifying tidal habitats based on tidal restriction features and function (LCEP 2009) and are consistent with those used in the large river delta mapping effort (Hall et al. 2021). These ratings included unrestricted, partially restricted, significantly restricted, completely restricted, or unknown restriction to tidal connectivity based on their feature type and status (see Table 3 for detailed definitions and descriptions). Certainty ratings for tidal connectivity classifications were also assigned and were based on feature type classifications and certainties, aerial imagery, and supplemental data evidence.

(6) Updating features from regional reviewers' comments

During dataset review, regional reviewers provided comments on features where they had additional knowledge, such as restoration activities, removals, or natural events that could impact a feature's status, type, or connectivity. After the review, comments were categorized into verification categories for both tidal restrictions and tidally influenced extents datasets to track changes:

- feature misclassified in database,
- unknown feature identified,
- feature missing from database,
- feature does not exist,
- feature has been added (since time of mapping),
- feature has been updated (from restoration or development),
- feature removed (from restoration or development),
- feature classification verified,
- feature extent or location incorrect, and
- other.

Features classified as **misclassified in the database** were updated per reviewer comments, with previous status, type, or connectivity recorded. Features marked as **missing from the database** or **added (since time of mapping)** were newly created, with reviewer comments retained and a note about the edits. For **classification verification**, no changes were made, but comments were retained with an edit note. Features categorized as **updated (from restoration or development)** or **removed (from restoration or development)** were revised accordingly, with previous status and tidal connectivity attributes recorded. Features categorized as **feature extent or location incorrect** were manually adjusted, with reviewer comments retained and an edit note added. Comments regarding tidally influenced habitat type were categorized as **other**, with a note indicating these updates will occur in a later phase. Features where reviewers confirmed **a feature did not exist** were categorized as **feature does not exist** and removed from the dataset to avoid confusion with features removed due to restoration or development. For **unknown feature identified**, meaning the feature was not captured through aerial imagery or regional data, it was added to the dataset and attributed based on the reviewer's comment.



Figure B.10. Example of armor and railways mapped in the regional data along the Puget Sound nearshore and how the lines were synthesized in the updated shoreline tidal restriction database.



Figure B.11. Examples of the mapped water crossing feature types. 1) A channel spanning bridge classified as unrestricted. 2) A single breached levee section classified as a partial restriction. 3) A culvert classified as a significant restriction. 4) A non-channel spanning bridge classified as a partial restriction. 5) A SRT classified as a significant restriction. 6) A floodgate classified as a complete restriction.

Table B.9. Status used to describe tidal restriction primary and water crossing features.

Status	Description
Present	For both primary and water crossing features that were present in the aerial imagery, regional data, or in both sources.
Removed	For primary features, features that were mapped as removed in the regional data or that were mapped as present in the regional data but appeared to be removed in the aerial imagery with no flow paths or water crossings present. For water crossing features, features were identified as removed if noted in the regional data or no longer visible in the imagery with clear evidence of removal (e.g., open flow path).
Abandoned/Remnant	Primary features were classified as abandoned or remnant if the feature appeared partially removed or degraded but there was still evidence of infrastructure. Features were flagged for review for connectivity impacts.
Breached	For primary features that had been removed, as documented in the regional data or visible in the imagery, and a flow path or channel (e.g., open water crossing feature) was present.

Delineating potential tidally influenced extent

The PMEP extent represents the maximum potential extent of tidally influenced areas based on an elevation-based estuary extent model (EBEEM) that combined lidar digital elevation models (DEMs) and water level models, but it does not account for tidal connectivity (Brophy et al. 2019). For example, areas surrounded by a complete tidal restriction feature like a dike or levee that have elevation lower than predicted maximum tidal elevations would be delineated in the PMEP tidal exceedance polygons. However, the extents of the PMEP polygons are based on modern digital elevation models which exclude areas that have been filled and developed and do not represent the true historical tidal wetland extent.

The tidal restriction feature (primary and water crossing features) network were buffered using a fixed buffer width of 10 feet. The buffer was intended to represent the footprint of tidal restriction features in lieu of digitizing the entire footprint from aerial imagery, which would also require elevation datasets to accurately delineate. We used the difference tool to remove the buffered tidal restriction network from the potential tidal extent and segment the resulting tidally influenced polygons. We then used the tidal restriction connectivity ratings to attribute connectivity to the resulting tidally influenced extent polygon network with feature and landscape tidal connectivity classifications. Tidally influenced extents were also segmented and delineated by landscape connectivity.

Tidally influenced areas were given certainty ratings for connectivity. If the tidal restrictions that influenced connectivity to a tidally influenced area had low certainty ratings for connectivity, tidally influenced connectivity ratings were also low certainty. All tidally influenced extents delineated by PMEP tidal exceedance extent were given high certainty ratings, except where the extent was manually corrected using remote sensing or aerial imagery.

Tidal restriction and tidally influenced area features were assigned unique identifiers and were spatially joined to create a crosswalk table relating polygon features to the tidal restrictions that surround them. This allows tidally influenced areas to be evaluated by restrictions that surround them, as well as allowing tidal restrictions to be evaluated based on their associated tidally influenced areas. This also allows for the length of restrictions to be totaled by their connectivity impacts for each individual polygon. Methods for generating this crosswalk are available in Appendix D: Digitizing Methods.

Data structure

Table B.10. Data form for CFS tidal restriction inventory. All features were digitized into a geopackage, and the following data was retained for them.

Feature Class	Field	Description	Values
Feature overview	Data ID	Unique ID that will ID the data feature and be used to join the feature with the original data source feature attributes. All source datasets have a DataID as well.	
	Data source general	Regional data, Aerial imagery, Regional review, Field validation	
	TR_ID	Tidal restriction ID assigned to all primary and water crossing tidal restriction features	
	Lead Entity Area	Deschutes, Green/Duwamish/Central PS, Hood Canal, Island, Kennedy, LW/Cedar/Sammamish, Nisqually, Nooksack, North Olympic Peninsula, Pierce County, San Juan, Skagit, Snohomish, Stillaguamish, West Sound	
	Chinook Recovery Watershed	Elwha, Dungeness, Mid-Hood Canal, West Sound, Skokomish, South Sound, Nisqually, Puyallup-White, Duwamish/Green, LW/Cedar/Sammamish, Snohomish, Stillaguamish, Skagit, Nooksack, San Juan, Island. Note: This attribute is no longer used in regional planning/coordination – use Lead Entity Area instead.	
	Source data year	Year the data were generated from the regional data	Year
	Modification date	Date modified by CFS, if data was not modified, then NULL.	Date, NULL
	Modification type	If data was altered by CFS by to match the aerial imagery (manual correction/alignment), other data layers (snapped alignment), or copied as is (none)	
Primary Feature	Existence certainty	Level of certainty that the feature exists. Features documented in the regional data and visible or clearly visible in the aerial imagery were given a High certainty rating. If the regional data conflicted with what was visible in the aerial imagery or the feature is not clearly visible in, the aerial imagery the feature was flagged for review and given a Low certainty rating.	

	Feature type	Primary feature types based on previous regional data or aerial imagery: Roads, Railroads, Dikes/levees, Unmapped roads, Armored/filled, Unknown. Unmapped roads refer to agricultural or unpaved roads that are not included in roads datasets.
	Feature certainty	Level of certainty that the primary was correctly identified. A High certainty rating was assigned to the feature if feature was mapped in regional data or clearly visible in the imagery (e.g., roads, railways). If the regional data conflicts with what is visible in the aerial imagery, the feature was given Low certainty and flagged for review. For dikes/levees and armored features identified in imagery a Low certainty was given.
	Feature status	All features were Present unless identified as Removed, Remnant/Abandoned, or Breached in the data, aerial imagery, or validation. Breached refers to primary features that were removed or damaged and have visible flow (WCF).
	Armored	All armor structures are Y unless removed or low certainty/unknown. For primary structures that run adjacent to a beach strategies feature or the PMEP, then Y . For roads and railways along the shoreline but not mapped in an armor database, then N . For features along the PMEP/shoreline that aren't clearly visible then Not Visible/Unknown . For features not along the shoreline, then NA .
All tidal restrictions (Primary or water-crossing feature)	Feature connectivity	Classifies the potential impacts the feature has on tidal connectivity.
		Unrestricted: Indicates that the feature does not impair tidal connectivity, used for buried pipes and bridges and breaches with spans that exceed natural channel width. This was also used for breached and/or removed dike and levee features that are part of a full primary feature removal along a polygon boundary. Partial: This was used for all docks and piers and bridges with spans that were less than the natural channel width. Individual beaches and removed features were also classified as partial restrictions unless part of a larger removal that span the polygon boundary. Significant: This classification largely relied on feature type classifications. Culverts, enclosed pipes, and SRTs and other tidal muting structures that are designed to remain open during part of the tidal cycle or culverts that allow some but significantly muted tidal connectivity. Remnant or unmaintained levees with multiple breaches were classified as significant restrictions. Complete: All intact levees and dikes, roads, railways, and armored/filled banks and for floodgates that are designed (or are in a damaged/degraded condition) to block tidal flooding and only provide drainage. All gravity drains were classified as complete restrictions. Unknown: Features not in the regional data and unable to be identified in the imagery.

	Connectivity certainty	Tidal connectivity was classified based on feature type information. If the feature was classified as present and high certainty for presence and type, the connectivity certainty was High . If the feature was classified as low certainty for presence or type, or as possibly removed or breached, then the connectivity certainty was Low .
	Comments	General comments
	Status	Flagged for review, See notes
	Aerial visibility	If the feature was visible in the aerial imagery, Yes , otherwise No
	Installation date	The date the feature was installed, if available
	Installation source	The source of the feature installation, if available
	Modifications	Descriptions of modifications made to the feature (removed, breached, restored), if available.
	Modification source	Source for the feature modification data, if available.
	Modification date	Date the feature was modified, if available.
	WCF ID	Unique ID that will ID the data feature and be used to join the feature with the original data source feature attributes. All source datasets have a DataID as well.
Water crossing feature	WCF existence certainty	The existence certainty was assigned as High if clearly visible in the imagery or in the regional data, otherwise was Low .
	WCF type certainty	The feature type certainty was assigned as High if clearly visible in the imagery or in the regional data, otherwise was Low .
	WCF status	Features were classified as Present, Removed, Abandoned , or Unknown . Abandoned features were identified in the regional data.
	WCF comments	Feature descriptions and other comments for external review.
	WCF Y/N	Yes if the feature was a water crossing, otherwise No .
	WCF type	Breach, Bridge, Buried pipe, Culvert, Dam, Enclosed pipe, Floodgate, Pump station, Unknown, SRT
	FPDSI Fish passage barrier rating	If the feature was included in the FPDSI it was given the passage rating from the database as Yes, No, or Unknown . If it was not included in the FPDSI, then the feature was classified as Not in the FPDSI as of the export date.

Field validation and review	FPDSI Site ID	WDFW FPDSI Site ID of the WCF
	FPDSI Export Date	Date the FPDSI was last exported to be used in the CFS database, all features in the database reflect the December 2020 FPDSI export
	Fishway present	Indicates whether a fishway is present, Yes/No
	Verification method	Method used to verify data. Local Expert, Ground, Regional database, or none. Regional database was used for additional information provided by a regional expert in response to review.
	Verification category	Category of reviewer or field verification results. Feature misclassified in database, Unknown feature identified, Feature missing from database, Feature doesn't exist, Feature has been updated (from restoration or development), Feature added (since time of mapping), Feature removed (from restoration or development), Feature classification verified, Feature extent or location incorrect, Other
	Previous feature classification	Previous primary or WCF feature classification, prior to review or validation, if updated
	Previous feature connectivity	Previous connectivity classification, prior to review or validation, if updated
	Previous feature status	Previous feature status, prior to review or validation, if updated
	Review date	Date of regional review, if applicable
	Reviewer name	Name of reviewer who provided comments, if applicable
	Reviewer comment	Comments from regional reviewer on feature, if applicable
	Review results	Results from review, past classification details, if applicable
	Field verification date	Date of field verification, if applicable
	Field verification results	Results from field verification, past classification details, if applicable

Calculated fields	Field verification comments	Other comments on field verification results, if applicable	
	Latitude	Latitude of center point of feature (calculated using GIS)	Decimal degrees
	Longitude	Longitude of center point of feature (calculated using GIS)	Decimal degrees
	BufferZone	Beach Strategies NGF 0-200ft, PMEP, PMEP 0-200ft buffer, Seaward aerial imagery, Aerial imagery pocket estuary	
	NGF Shoreform ID	ID corresponding to NGF shoreform polygon	
	Feature length	Linear length (calculated using GIS)	Feet
	NGF Shoreform	Shoreform from Beach Strategies NGF	
	Elevation zone	Tidal elevation, relative to mean low and high water tidal datums	

Table B.11. Data entry form for CFS tidally influenced extent inventory. All tidally influenced extent features were digitized into a geopackage and a geodatabase, and the following data were retained.

Feature Class	Field	Description	Values
All features	DataID	DataID for PMEP layer.	
	LE_ID	Unique feature ID assigned to each tidally influenced extent feature using the Lead Entity Area name and a unique number.	
	CRW	Chinook Recovery Watershed the feature is located within	Elwha, Dungeness, Mid-Hood Canal, West Sound, Skokomish, South Sound, Nisqually, Puyallup-White, Duwamish/Green, LW/Cedar/Sammamish, Snohomish, Stillaguamish, Skagit, Nooksack, San Juan, Island
	Lead Entity Area	Lead Entity Area the feature is located within	Deschutes, Green/Duwamish/Central PS, Hood Canal, Island, Kennedy, LW/Cedar/Sammamish, Nisqually, Nooksack, North Olympic Peninsula, Pierce County, San Juan, Skagit, Snohomish, Stillaguamish, West Sound
	Data source	The data source of the mapped tidally influenced extents	PMEP, Aerial Imagery, Other
	Elevation zone	Tidal elevation zone	Above Mean Higher High Water, Below Mean Higher High Water
	Average elevation	Average elevation calculated from zonal statistics using DEM data	Feet (to be calculated in GIS)
	Source data year	Year the data were generated from the regional data.	
	Feature perimeter	Perimeter calculated using GIS	Feet (to be calculated in GIS)
	Feature area	Area calculated using GIS	Square feet (to be calculated in GIS)
	Latitude	Latitude of center point of feature	Decimal degrees (to be calculated in GIS)
	Longitude	Longitude of center point of feature	Decimal degrees (to be calculated in GIS)
	Modification date	Date modified by CFS, if data was not modified, then NULL.	Date, NULL
	Modification type	If data was altered by CFS by to match the aerial imagery (manual correction/alignment), other data layers (snapped alignment).	None, Manual Correction/Alignment, Snapped Alignment
	River Name	If tidally influenced extent was near a river, name of the river, if named	Name of the river if named, NULL

Landscape tidal connectivity impacts

Classifies the tidal connectivity of the tidally influenced feature based on the connectivity of the tidally influenced extent feature downstream of that feature and the downstream tidal restriction features. Tidally influenced extents will at best be rated the same as the downstream tidally influenced extent feature, and then rated based on their tidal restrictions connectivity.

Completely Restricted Non-Tidal: Indicates that a feature completely blocks tidal connectivity and tidal processes. Impoundments and simple channel morphology above features with no apparent sign of tidally influenced habitat.

Significantly Restricted Tidal: Tidally influenced extents directly upstream of significant tidal restrictions or upstream of a significantly restricted tidally influenced extents and upstream of an unrestricted, partial, unknown, or significant restriction were called significantly restricted.

Partially Restricted Tidal: Tidally influenced extents directly upstream (landward) of partial tidal restrictions or upstream of a partially restricted tidally influenced extents were classified as partially restricted for landscape connectivity. All tidally influenced extents upstream of non-channel spanning bridges and breaches and removed features were called partially restricted for their landscape tidal connectivity rating, unless they were upstream of a more restricted tidally influenced extent, in which case their connectivity was determined by that extent's rating. Tidally influenced extents surrounded by OWS were called partially restricted, unless upstream of a significantly or completely restricted tidal restriction or tidally influenced extent.

Completely Restricted Non-Tidal, Significantly Restricted Tidal, Partially Restricted Tidal, Unrestricted, Developed, Unknown, Nearshore Deep - Unrestricted, Nearshore Deep - Partially Tidal Restricted, Nearshore Shallow - Unrestricted, Nearshore Shallow - Partially Tidal Restricted

Unrestricted: Tidally influenced extents were classified as unrestricted for landscape connectivity if all surrounding and downstream (seaward) extents were open to tidal flooding. Features upstream of tidally influenced extents were classified as unrestricted and with at least one unrestricted water crossing or removed primary feature (e.g., channel spanning bridges, breached primary and removed primary features) were classified as unrestricted.

Developed: Areas mapped in the PMEP but were filled or developed and often had visible overland structures such as houses were given a developed rating.

Unknown: This indicates that the connectivity impacts cannot be determined from remote sensing or the compiled regional data. Features upstream of tidal restriction features with unknown connectivity restrictions were given an unknown rating.

Nearshore Deep - Unrestricted or Partially Tidally

Restricted: Seaward area within 1,000 ft of +1 m MHW line (derived from NOAA 3m bathymetry data clipped to the DOE and DNR shoreline (NWIFC 2023)) that had a depth of ≤ -4 m MHW. If Nearshore Intertidal area extends seaward $\geq 1,000$ ft, there will not be a mapped subtidal polygon for that section of shoreline, Nearshore Deep areas were assumed to have Unrestricted tidal connectivity unless between OWS feature and were assumed to be partially tidally restricted.

Nearshore Shallow - Unrestricted or Partially Tidally

Restricted:: Seaward areas within 1,000 ft of the landward boundary of intertidal extent (+1 m MHW that are within -4 to +1 meters MHW (derived from NOAA 3m bathymetry data clipped to the DOE and DNR shoreline (NWIFC 2023)). All features were assumed to have Unrestricted tidal connectivity, but note that overwater structures may influence tidal processes in these habitats.

Landscape tidal connectivity impacts certainty	Tidal Connectivity certainty downstream ratings will be given based on the certainty ratings of the tidal restriction features from which the connectivity was derived and the downstream polygon's certainty ratings.	High, Low
Feature tidal connectivity impacts	Classifies the tidal connectivity of the feature based on the drainage connectivity to that feature and the tidal restriction features. Completely Restricted Non-Tidal: Tidally influenced extents upstream of or surrounded by complete tidal restrictions, such as dikes and levees, roads, railways, or completely restricted primary tidal restriction and water crossing features, were classified as completely restricted non-tidal. Areas with less restrictive landward or upstream tidal restrictions were still called completely restricted non-tidal if tidal connectivity to the area was restricted. Tidally influenced extents were also called completely restricted if the feature was surrounded by areas outside of the PMEP boundary. Significantly Restricted Tidal: Tidally influenced habitats that were surrounded by tidal restriction features that only allow for significantly impacted hydrologic and tidal connectivity, such as some SRTs, culverts, and enclosed pipes were classified as significantly restricted tidal. Partially Restricted Tidal: Tidally influenced extents upstream of tidal restrictions with partially restricted connectivity were classified as partially restricted for feature connectivity based on the restriction features immediately surrounding the tidally influenced extent. This included tidally influenced extents upstream of breaches and bridges with spans less than the channel width, and SRTs restored to allow partially restricted tidal connectivity. OWS and tidally influenced extents surrounded fully by OWS were called partially restricted tidal.	Completely Restricted Non-Tidal, Significantly Restricted Tidal, Partially Restricted Tidal, Unrestricted, Developed, Unknown

Unrestricted: Tidally influenced extents were classified as unrestricted tidal for feature connectivity if they were open to tidal flooding via at least one unrestricted feature. Extents with full primary feature removals along the boundary were classified as unrestricted. Areas located landward/upstream of channel spanning bridges that allow for tidal connectivity underneath the bridge were also classified as unrestricted. Extents with tidal restriction features along the landward or upstream boundary of the tidal influenced extent were still classified as unrestricted if at least one unrestricted feature was present allowing tidal connectivity to the feature.

Developed: Areas mapped in the PMEP but were filled or developed and often had visible overland structures such as houses were given a developed rating.

Unknown: This indicates that the connectivity impacts cannot be determined from remote sensing or the compiled regional data. Features upstream of tidal restriction features with unknown connectivity restrictions were given an unknown rating.

	Feature tidal connectivity impacts certainty	High and low certainty ratings will be assigned based on the tidal restriction certainty that the connectivity rating was assigned.	High, Low
	Comments	Description, other comments for external review	
	Status	Flags for data review	Requires internal review, Requires field verification, See notes, NULL
	Modifications	Feature modifications made (removal, breach, etc.)	
	Modification source	Source of information for modifications that have been made to the feature	
	Modification date	Date the feature was modified	Date, NULL
Review	Previous connectivity classification	Previous feature classification	Completely Restricted Non-Tidal, Significantly Restricted Tidal, Partially Restricted Tidal, Unrestricted, Developed, Unknown

Verification method	Method used to verify data. Regional database was provided by a regional expert in response to review, local expert refers to regional review, boat and ground refer to field verification	Regional database, Local expert, Boat, Ground
Verification category	Category of reviewer feedback	Feature misclassified in database, feature missing from database, feature doesn't exist, feature has been updated (from restoration or development), feature added (since time of mapping), feature removed (from restoration or development), feature classification verified, feature extent or location incorrect, other
Review date	Date of review	Date, NULL
Reviewer name	Name of reviewer who provided comments	
Reviewer comment	Comments from reviewer on feature, or whether feature was added or remove pending review	
Review results	Results from review, past classification details	
Field verification ID	Unique ID that joins field surveyed data with the database	
Field verification date	Date of field verification	Date, NULL
Field verification results	Comments on the results of field verification	
Verification results - feature connectivity	Feature tidal connectivity: Field verification for feature tidal connectivity, whether connectivity was correctly classified.	Completely Restricted Non-Tidal, Significantly Restricted Tidal, Partially Restricted Tidal, Unrestricted, Developed, Unknown
Verification results - landscape connectivity	Downstream tidal connectivity: Field verification for downstream tidal connectivity, whether connectivity was correctly classified.	Completely Restricted Non-Tidal, Significantly Restricted Tidal, Partially Restricted Tidal, Unrestricted, Developed, Unknown

Table B.12. Data entry form for data reviewers. Reviewers filled out the following using a password protected Arc Online Data portal using a unique login that tracked reviewer name and date of review.

	Description
Feature ID	The Feature ID (TR_ID for tidal restrictions and TW_ID for polygons) of feature reviewed or left blank if a general data structure comment or missing feature.
Feature Comment	General comments on features
Feature existence - Comment	Comments on the existence of the feature and certainty
Feature type - Comment	Comments on feature types
Feature connectivity - Comment	Comments on feature connectivity, including comments on rules for assigning connectivity
Other	Any other comments on data structure

APPENDIX C: RESULTS

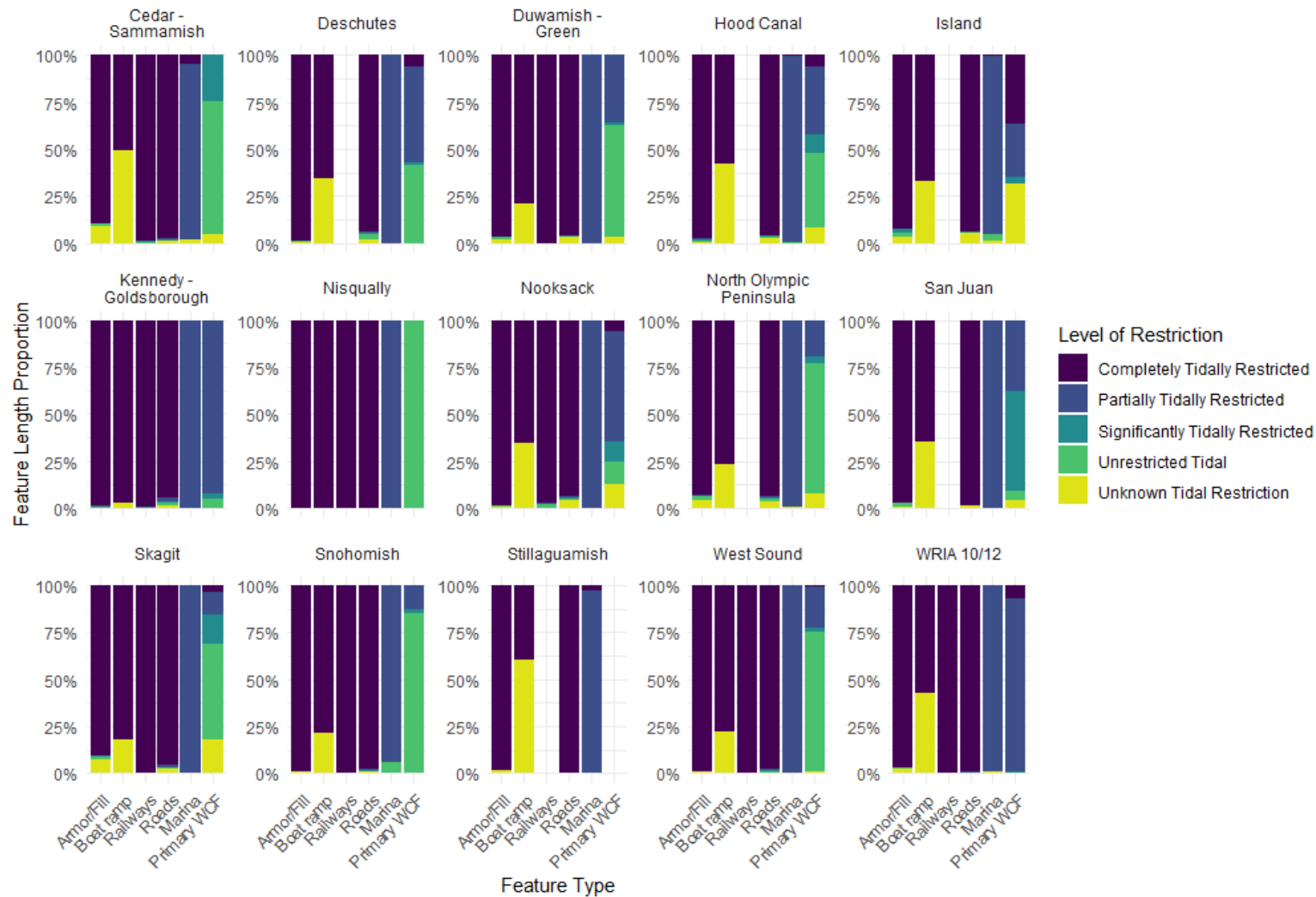


Figure C.1. Proportion of tidal restriction length by tidal connectivity ratings for feature types broken out by Lead Entity area.

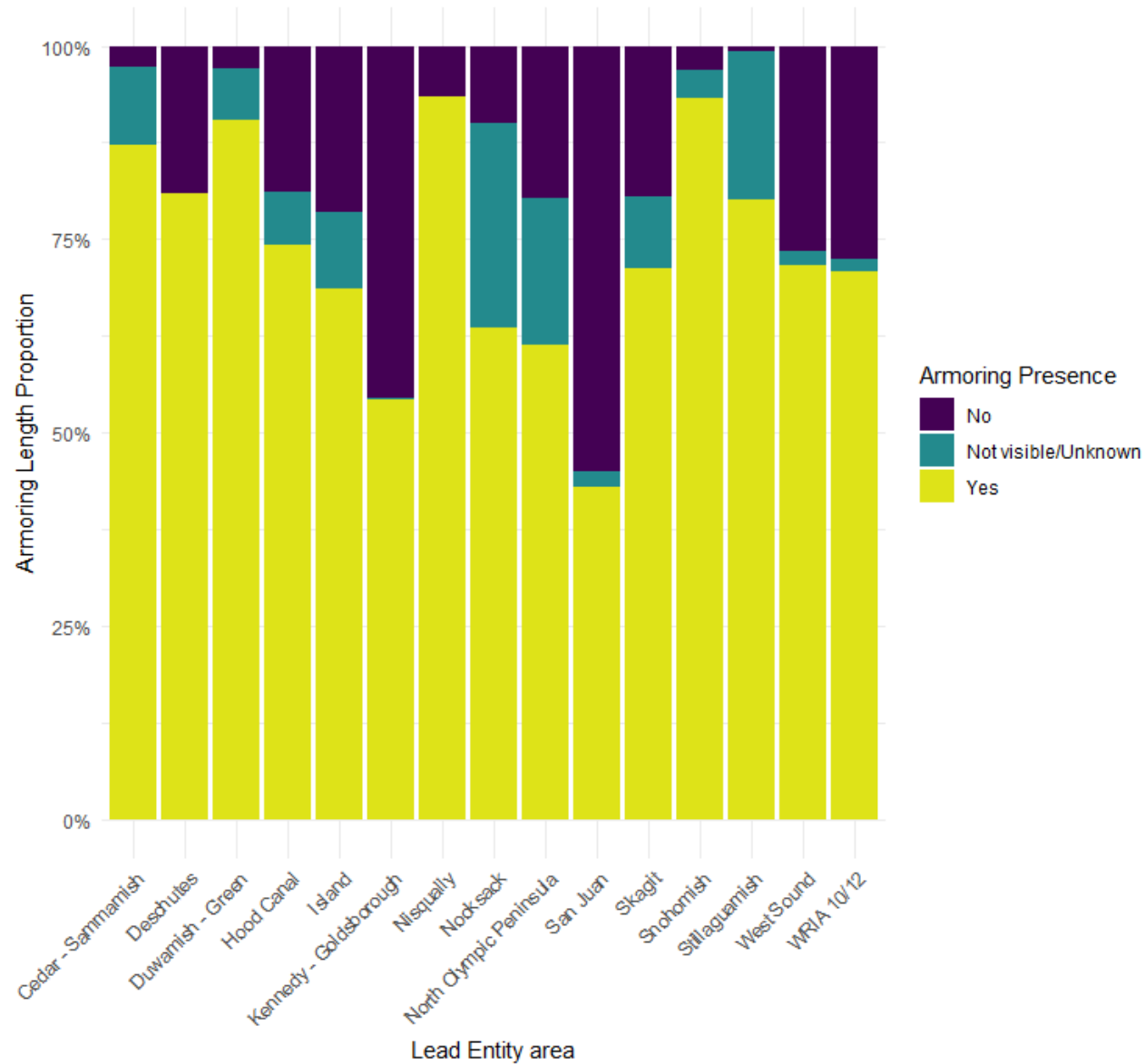


Figure C.2.Proportion of armoring and armored tidal restriction feature length throughout Puget Sound by Lead Entity area.

Table C.13. Total feature lengths (kilometers) for primary (e.g., road, boat ramp, armor/fill, etc.), primary with water crossing feature (WCF) (e.g., road with a culvert, etc.), and only WCF) by connectivity impacts for nearshore tidal restrictions (excluding the large river deltas) in the LE areas. Primary features classified by if they were armored, if they were along a waterfront or PMEP boundary but armor wasn't present or wasn't visible, NA refers to features that were not immediately adjacent to or intersecting the PMEP area.

Lead Entity Area	Type of Feature	Armored?	Tidal Restriction Connectivity Rating					Total
			Completely Tidally Restricted	Partially Tidally Restricted	Significantly Tidally Restricted	Unknown Tidal Restriction	Unrestricted Tidal	
Cedar - Sammamish	Primary	NA	58.351	0.13	-	1.48	0.09	60.05
		No	0.935	-	-	0.04	0.28	1.26
		Not visible/Unknown	4.409	-	0.12	0.20	-	4.72
		Yes	39.446	-	-	0.22	-	39.66
	Primary with WCF	NA	0.01	0.02	0.01	0.03	0.40	0.47
		No	-	-	-	-	0.05	0.05
		Not visible/Unknown	0.014	0.01	-	0.006	-	0.03
		Yes	0.999	-	0.09	0.10	-	1.19
	Only WCF		-	13.72	0.10	0.19	0.29	14.31
Deschutes	Primary	NA	2.894	-	-	0.15	-	3.04
		No	8.25	-	-	0.49	0.14	8.88
		Yes	39.117	-	-	0.04	-	39.15
	Primary with WCF	NA	-	0.01	-	0.01	0.24	0.26
		No	-	0.02	0.09	0.01	0.17	0.29
		Yes	0.008	-	0.02	0.004	-	0.03
	Only WCF		0.069	3.20	0.02	-	0.47	3.76
Duwamish - Green	Primary	NA	80.863	-	-	2.43	-	83.29
		No	1.301	-	-	0.25	1.43	2.98
		Not visible/Unknown	5.345	-	-	1.15	0.10	6.59
		Yes	94.037	-	-	1.09	-	95.13
	Primary with WCF	NA	0.005	0.34	0.03	0.04	0.09	0.50
		No	-	-	0.01	-	-	0.01
		Not visible/Unknown	-	0.51	-	0.03	-	0.54
		Yes	0.037	0.02	0.05	0.05	-	0.16
	Only WCF		-	17.23	0.01	0.02	0.37	17.63
Hood Canal	Primary	NA	247.044	-	-	4.36	-	251.41
		No	35.793	0.63	0.55	3.31	0.49	40.77
		Not visible/Unknown	11.937	-	0.53	3.62	-	16.09
		Yes	174.317	-	-	0.99	-	175.30
	Primary with WCF	NA	-	2.83	0.69	0.07	0.30	3.90
		No	0.006	0.13	0.33	0.03	3.40	3.91
		Not visible/Unknown	0.034	0.05	0.02	0.03	0.11	0.24
		Yes	0.063	0.65	0.44	0.12	0.26	1.54
	Only WCF		0.093	35.72	0.09	0.13	0.44	36.47
Island	Primary	NA	193.8	-	0.32	9.99	-	204.11

		No	26.009	-	1.83	2.79	1.72	32.35
		Not visible/Unknown	12.403	0.02	0.07	2.53	-	15.03
		Yes	99.65	-	1.16	3.34	-	104.15
	Primary with WCF	NA	0.202	0.51	0.62	0.09	-	1.42
		No	0.046	0.04	0.11	0.02	0.10	0.31
		Not visible/Unknown	0.004	-	0.01	0.02	-	0.03
		Yes	0.135	0.02	0.07	0.04	0.03	0.28
	Only WCF		0.142	12.78	0.01	0.26	0.50	13.69
Kennedy - Goldsborough	Primary	NA	10.938	-	-	0.02	-	10.95
		No	56.722	0.61	-	1.14	0.51	58.97
		Not visible/Unknown	0.245	-	-	0.17	-	0.42
		Yes	72.14	-	-	0.02	-	72.16
	Primary with WCF	NA	-	0.08	0.07	-	-	0.15
		No	-	0.71	0.40	0.05	0.71	1.86
		Yes	-	0.45	0.02	0.01	-	0.48
	Only WCF		-	6.36	0.01	-	0.02	6.39
Nisqually	Primary	NA	2.107	-	-	-	-	2.11
		No	0.087	-	-	-	-	0.09
		Yes	1.242	-	-	-	-	1.24
	Only WCF		-	0.01	-	-	0.02	0.03
Nooksack	Primary	NA	132.349	-	-	4.24	0.57	137.15
		No	8.286	-	-	1.43	0.08	9.79
		Not visible/Unknown	24.075	-	-	1.88	-	25.96
		Yes	61.003	-	0.04	-	0.002	61.05
	Primary with WCF	NA	0.023	2.14	0.22	0.10	1.08	3.56
		No	0.02	0.03	0.03	0.01	-	0.09
		Not visible/Unknown	0.008	-	0.05	0.03	0.03	0.12
		Yes	0.028	1.67	0.06	0.004	-	1.76
North Olympic Peninsula	Primary	NA	63.486	-	0.24	1.64	-	65.37
		No	15.187	-	0.22	1.79	0.52	17.71
		Not visible/Unknown	15.393	-	-	1.78	-	17.18
		Yes	54.242	-	-	0.92	0.86	56.02
	Primary with WCF	NA	-	0.42	0.19	0.17	0.62	1.39
		No	-	0.03	0.22	0.04	0.15	0.43
		Not visible/Unknown	-	0.06	0.04	0.03	0.14	0.27
		Yes	0.038	0.17	0.12	0.02	0.02	0.37
San Juan	Primary	NA	43.012	-	-	1.09	-	44.10
		No	56.55	-	0.09	0.15	0.49	57.28
		Not visible/Unknown	1.425	0.01	-	0.74	-	2.18
		Yes	44.817	-	-	0.03	0.13	44.98
		NA	-	0.06	0.006	0.01	-	0.07

	Primary with WCF	No	-	0.35	0.02	0.03	-	0.40
		Yes	-	-	0.01	0.01	-	0.02
	Only WCF		-	42.30	0.16	0.01	0.02	42.49
Skagit	Primary	NA	76.134	-	-	1.17	0.29	77.59
		No	11.376	-	0.46	2.22	0.59	14.63
		Not visible/Unknown	6.656	-	-	0.80	-	7.45
		Yes	55.336	-	-	1.85	-	57.18
	Primary with WCF	NA	0.015	5.03	0.06	0.10	0.40	5.60
		No	0.01	0.76	0.02	-	0.24	1.02
		Not visible/Unknown	-	-	-	0.01	-	0.01
		Yes	0.047	0.02	0.06	0.03	-	0.16
	Only WCF		0.005	18.62	0.02	0.08	0.07	18.79
Snohomish	Primary	NA	37.17	-	-	0.19	-	37.36
		No	0.96	-	-	0.14	-	1.10
		Not visible/Unknown	0.87	-	-	0.24	-	1.11
		Yes	32.313	-	0.05	0.13	-	32.50
	Primary with WCF	NA	0.031	-	0.01	0.02	-	0.06
		No	-	-	0.01	-	-	0.01
		Not visible/Unknown	-	0.13	0.004	-	-	0.13
		Yes	0.003	-	0.03	0.04	-	0.07
	Only WCF		-	17.95	0.01	0.02	1.60	19.58
Stillaguamish	Primary	NA	4.31	-	-	-	-	4.31
		No	-	-	-	0.03	-	0.03
		Not visible/Unknown	0.847	-	-	0.07	-	0.92
		Yes	3.809	-	-	-	-	3.81
	Primary with WCF	NA	0.002	-	0.01	-	-	0.02
		Yes	0.015	-	-	0.01	-	0.02
	Only WCF		-	0.42	-	-	-	0.42
West Sound	Primary	NA	144.101	-	-	0.82	-	144.92
		No	105.5	-	0.11	1.20	0.63	107.45
		Not visible/Unknown	6.472	-	-	1.12	-	7.59
		Yes	293.979	-	-	0.60	0.10	294.68
	Primary with WCF	NA	0.036	1.07	0.55	0.09	0.97	2.73
		No	0.037	1.39	0.50	0.14	0.48	2.55
		Not visible/Unknown	-	-	0.002	-	-	0.002
		Yes	0.029	1.40	0.16	0.13	0.38	2.09
	Only WCF		0.049	83.69	0.09	0.03	3.62	87.47
WRIA 10/12	Primary	NA	50.451	-	-	0.42	-	50.87
		No	19.833	-	-	-	-	19.83
		Not visible/Unknown	0.627	-	-	0.52	-	1.15
		Yes	52.374	-	-	0.24	0.08	52.69
	Primary with WCF	NA	-	0.38	0.06	-	0.08	0.52
		No	-	0.55	0.27	-	-	0.82

		Not visible/Unknown	0.002	-	0.002	-	-	0.004
		Yes	0.022	0.02	0.22	0.01	-	0.27
	Only WCF		0.032	12.76	0.01	0.10	-	12.89
All Lead Entity Areas	Primary	NA	1147.01	0.13	0.56	27.99	0.94	1176.63
		No	346.789	1.23	3.25	14.99	6.87	373.13
		Not visible/Unknown	90.704	0.04	0.71	14.82	0.10	106.37
		Yes	1117.822		1.25	9.46	1.17	1129.70
	Primary with WCF	NA	0.324	12.89	2.53	0.72	4.18	20.64
		No	0.119	4.01	1.99	0.32	5.30	11.74
		Not visible/Unknown	0.062	0.75	0.13	0.14	0.28	1.36
		Yes	1.424	4.43	1.34	0.56	0.69	8.44
	Only WCF		0.413	310.43	0.61	1.06	8.06	320.57

Table C.14. Total lengths (kilometers) of tidal restrictions grouped by their tidal connectivity rating for each LE area.

Lead Entity Area	Tidal Connectivity Impact					Total
	Completely Tidally Restricted	Partially Tidally Restricted	Significantly Tidally Restricted	Unknown Tidal Restriction	Unrestricted Tidal	
Cedar - Sammamish	104.2	13.9	0.3	2.3	1.1	121.7
Deschutes	50.3	3.2	0.1	0.7	1.0	55.4
Duwamish - Green	181.6	18.1	0.1	5.1	2.0	206.8
Hood Canal	469.3	40.0	2.6	12.7	5.0	529.6
Island	332.4	13.4	4.2	19.1	2.4	371.4
Kennedy - Goldsborough	140.0	8.2	0.5	1.4	1.2	151.4
Nisqually	3.4	0.0	-	-	0.0	3.5
Nooksack	225.8	34.0	0.4	7.7	1.8	269.8
North Olympic Peninsula	148.3	16.2	1.1	6.5	2.9	175.0
San Juan	145.8	42.7	0.3	2.1	0.6	191.5
Skagit	149.6	24.4	0.6	6.2	1.6	182.4
Snohomish	71.3	18.1	0.1	0.8	1.6	91.9
Stillaguamish	9.0	0.4	0.0	0.1	-	9.5
West Sound	550.2	87.5	1.4	4.1	6.2	649.5
WRIA 10/12	123.3	13.7	0.6	1.3	0.2	139.1
Total	2704.7	333.9	12.4	70.1	27.6	3148.6

Table C.15. Feature area (hectares) of nearshore tidally influenced extent (excluding the large river deltas and nearshore shallow and deep extents) by LE Area and landscape connectivity impacts.

Lead Entity Area	Landscape Connectivity Rating						Total
	<i>Completely Restricted Non-tidal</i>	<i>Developed</i>	<i>Partially Restricted Tidal</i>	<i>Significantly Restricted Tidal</i>	<i>Unknown</i>	<i>Unrestricted Tidal</i>	
Cedar-Sammamish	5.42	5.47	0.386	11.1	-	65.6	88.0
Deschutes	1.4	0.442	10.4	11.1	3.06	291	317.4
Duwamish-Green	6.61	2.4	4.44	0.497	0.378	68.7	83.0
Hood Canal	67.9	11	17.2	24.7	28.4	1321	1470.2
Island	992	119	92.7	6.99	23.4	316	1550.1
Kennedy-Goldsborough	0.357	1.39	13.8	2.03	5.07	493	515.6
Nooksack	179	70.7	131	3.44	17.9	1358	1760.0
North Olympic Peninsula	17.9	2.38	12.3	9.42	16.6	3482	3540.6
San Juan	38.6	8.54	1.92	48.1	31.6	210	338.8
Skagit	120	18.1	4.48	7.96	13.3	394	557.8
Snohomish	3.76	12.4	1.04	2.98	0.096	244	264.3
Stillaguamish	0.967	1.6	-	-	-	1.92	4.5
Pierce	1.27	4.91	3.32	22.1	7.81	22	61.4
West Sound	2.25	26	54.2	60.3	61	1925	2128.8
Total	1437.4	284.3	347.2	210.7	208.6	10,192.2	12,680.5

APPENDIX D: DIGITIZING METHODS

(1) General Tidal Restriction Mapping:

- a. **Objective.** To map tidal restrictions for all of Puget Sound using existing regional data and aerial imagery, eliminating duplicate features and correcting misalignments in the regional data.
- b. **Input layers.** Current aerial imagery (e.g., Google Earth, Hexagon Imagery Program 0.3 m 4-band aerial imagery 2017) and oblique shoreline imagery (DOE 2016) as needed for remote sensing and interpretation; elevation data (e.g., LiDAR DEMs or PMEP Tidal Exceedance layers) as available or needed to map boundaries of tidal influence; existing regional habitat, infrastructure, and hydrology layers. Input layers are required to be in Washington State Plane South NAD 83 HARN (EPSG 2927) coordinate system.
- c. **Data Inventory.** A single vector layer will contain the mapped features for tidal restrictions. Input layers are required to be in Washington State Plane South NAD 83 HARN (EPSG 2927) coordinate system. The data entry form is shown in Table B.10.
- d. **Adding polygon features.** Polygon features will be copied from existing regional data sets and “heads- up digitized” on screen as lines using the mouse to manually align features with the aerial imagery or snap the features to other regional data layers, or both. All lines should be mapped at a maximum of 1:1,000 scale based on available data sets.
 - a. **Adding features from regional data**
 - **QGIS**
 - I. Right-click the Tidal Restriction vector feature layer > *Toggle editing*
 - II. Click the vector feature layer and use the Selection Tool to select the feature to be copied.
 - III. [Edit]> *Copy Features*
 - IV. Select the Tidal Restriction vector feature layer>[Edit]>*Paste Features*
 - V. Attribute appropriate fields – see Table B.10 for list
 - b. **Adjusting existing features**
 - **QGIS**
 - I. Right-click the Tidal Restriction vector feature layer > *Toggle editing*
 - II. [Digitizing Toolbar]> *Vertex Tool*
 - III. Select location on the map (at 1:1000 scale) to modify vertex

- IV. Modify vertices until the feature is adequately characterized to the aerial imagery or regional data layers
- V. Right click to complete the line
- VI. Attribute appropriate fields – see Table B.10 for list
- VII. Fill out Aerial Imagery Y/N and Modification Type and Modification Date to indicate the feature was adjusted

c. **Adding new features**

- **QGIS**

- I. Right-click the Tidal Restriction vector feature layer > *Toggle editing*
- II. [Digitizing Toolbar]> *Add Line Feature*
- III. Select location on the map (at 1:1000 scale) to place a vertex
- IV. Place vertices until the feature is adequately characterized
- V. Right click to complete the line
- VI. Attribute appropriate fields – see Table B.10 for list
- VII. Fill out Aerial Imagery Y/N and Modification Type and Modification Date to indicate the feature was digitized from the aerial imagery

(2) Digitizing tidally influenced extent areas

- a. **Objective.** To map tidally influenced extents for the Puget Sound using mapped tidal restriction networks to determine connectivity and area.
- b. **Study area.** The PMEP Estuary Extent was used as the expected range of tidal influence and informed the potential and current wetland extent based on current topography.
 - The NWIFC Statewide Intertidal Areas dataset was Union-ed to the tidal the PMEP Estuary Extent. The Intertidal Areas layer was evaluated for places where it extended beyond the PMEP extent and polygons were manually removed if they were outside of the visible tidal extent.

d. **Adjusting existing features**

- **QGIS**

- I. Right-click the Tidally Influenced vector feature layer > *Toggle editing*
- II. [Digitizing Toolbar]> *Vertex Tool*
- III. Select location on the map (at 1:1000 scale) to modify vertex

- IV. Modify vertices until the feature is adequately characterized to the aerial imagery.
- V. Right click to complete the polygon
- VI. Attribute appropriate fields – see Table B.11 for list
- VII. Fill out Aerial Imagery Y/N and Modification Type and Modification Date to indicate the feature was adjusted

(3) Buffer tidal restriction network

- a. **Objective.** Buffer tidal restrictions by the average width of restriction features to segment tidally influenced extents.

- **QGIS**

- I. [Digitizing Toolbar]> *Buffer*

- 1.Distance= 10 feet
 - 2.Segments= 5
 - 3.End cap style= Round
 - 4.Join style= Round
 - 5.Miter limit= 2.0
 - 6.Dissolve result

- II. Saved as ***LEName***TidalRestrictions_Buffer.gpkg

(4) Segmenting tidally influenced extents using tidal restriction buffers

- a. **Objective.** Use buffered tidal restrictions to segment PMEP tidal estuary extent/Intertidal area into tidally influenced polygons attributed with connectivity ratings determined by tidal restrictions.

- **QGIS**

- I. QGIS Processing Toolbox> Difference

- Input layer: _PMEP _Intertidal.gpkg

- Overlay layer: ***LEName***TidalRestrictions_Buffer.gpkg

- II. QGIS Processing Toolbox> Multipart to singleparts

- >***LEName***TidallyInfluenced_singleparts.gpkg

- III. Right-click the Tidal Wetland template vector feature layer > *Toggle editing*

- IV. Click the **LEName**TidallyInfluenced_singleparts.gpkg layer and use the Selection Tool to select all features
- V. [Edit]> *Copy Features*
- VI. Select the Tidal Wetland template vector feature layer>[Edit]>*Paste Features*
- VII. Save as> **LEName**TidallyInfluenced_use.gpkg

(5) Tidal Restriction and Tidally Influenced Extent Crosswalk

- a. **Objective.** Create a crosswalk table to join tidal restriction features with the tidally influenced features they surround.

• **QGIS**

- I. Save **LEName**TidalRestrictions.gpkg
- II. Right-click the Tidal Restriction feature layer > *Toggle editing*
- III. QGIS Processing Toolbox>Buffer
 - a. Distance= 10.1 feet
 - b. Segments= 5
 - c. End cap style= Flat
 - d. Join style= Round
 - e. Miter limit= 2.0
- IV. QGIS Processing Toolbox>Saga Polygon Union
Input layer: **LEName**TidallyInfluenced_use.gpkg
Overlay layer: Buffer
- V. Intersections are all rows with both TB_ID and LE_ID>Deleted all other features
- VI. FID column>\$id
>**LEName**TidalInfluenced_TidalRestriction_Crosswalk

APPENDIX E: PROPOSED DECISION TREE FOR HABITATS

As mentioned above in the executive summary, we initially attempted to classify potential tidally influenced embayment and lagoonal habitat types into functional or geomorphic classifications (e.g., barrier lagoons, closed lagoons, etc.), but it was determined (through regional review) that additional coordination is needed to develop a consistent classification schema. Therefore, we propose this draft decision tree and plan to work with regional reviewers, technical advisory group, and project partners to establish a consistent classification for these habitat types.

PROPOSED DECISION TREE

