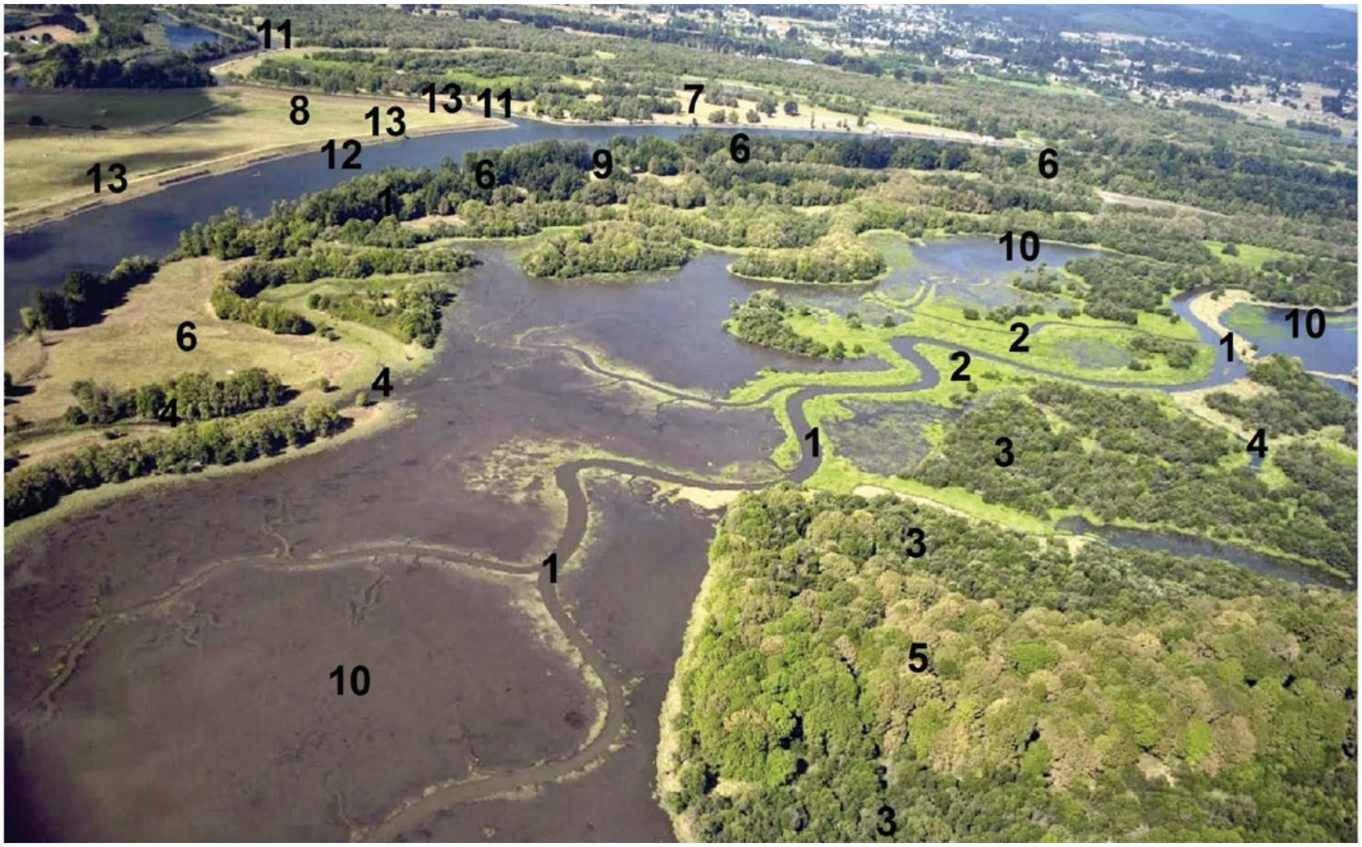
Lower Columbia Estuary Partnership

The Columbia River Estuary Ecosystem Classification

Supplying comprehensive information on landforms, vegetation, and manmade features in the Columbia River estuary



THE COLUMBIA RIVER ESTUARY ECOSYSTEM CLASSIFICATION inventories a highly diverse set of natural and manmade features—and the wide variety of processes that formed them—making it a valuable tool for research, monitoring, resource management, and restoration planning.

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Photo locations: Cover and frontispiece: Cunningham Slough on Sauvie Island, OR.

Back Cover: Marsh, Karlson, and Russian Islands. Cathlamet Bay, OR.

Features key:

ID	Complex	Catena	Biocatena	Anthropogenic
1	Crevasse Splay	Tie Channel	Tidal Deciduous Wetland	---
2	Crevasse Splay	Wetland	Tidal Herbaceous Wetland	---
3	Crevasse Splay	Wetland	Tidal Deciduous Wetland	---
4	Crevasse Splay	Floodplain Channel	Water	---
5	Crevasse Splay	Natural Levee	Tidal Deciduous Wetland	---
6	Floodplain Ridge and Swale	Natural Levee	Non-Tidal Deciduous Wetland	---
7	Floodplain Ridge and Swale	Natural Levee	Agricultural	---
8	Floodplain Backswamp	Lake Bed	Agricultural	---
9	Floodplain Backswamp	Wetland	Tidal Herbaceous Wetland	---
10	Floodplain Backswamp	Lake/Pond	Water	---
11	Floodplain	Floodplain Channel	Water	---
12	Tributary Secondary Channel	Permanently Flooded	Water	---
13	---	---	---	Levee

Acknowledgments

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- Keith Marcoe and Krista L. Jones — Lower Columbia Estuary Partnership
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Lower Columbia Estuary Partnership

USGS science for a changing world

WETLAND ECOSYSTEM TEAM UNIVERSITY OF WASHINGTON

What is the ecosystem classification?

The Columbia River Estuary Ecosystem Classification is a GIS-based system for classifying and mapping landforms and land cover types in the Columbia River estuary. Combining previously collected information and new data[1] the classification represents the most comprehensive, up-to-date inventory yet of the estuary's natural and manmade features and is suitable for use in research, monitoring, resource management, and restoration planning. The products of the classification—its high-resolution data and maps—are freely available to anyone seeking to better understand this unique landscape's physical features and ecosystems, how they formed, and what their future might be.

- Quantify baseline conditions and monitor changes
- Locate ecosystems of interest
- Understand spatial distributions
- Evaluate ecological metrics related to the amount, diversity, and fragmentation of ecosystems[2]
- Distinguish between ecosystems created by relatively infrequent geological events and those formed by more common processes
- Predict the ecological development of a site

The classification organizes and describes features large and small, created by forces ranging from tectonic to tidal. In many cases the classification links features to historical geologic events or to ongoing processes that continue to shape the modern estuary.

Who created the classification?

The Lower Columbia Estuary Partnership collaborated with geologists, wetland scientists, and GIS experts at the U.S. Geological Survey and University of Washington in developing the classification. Funding came from the Bonneville Power Administration and U.S. Army Corps of Engineers.

For more information

For more information or to access the classification, go to *www.estuarypartnership.org/columbia-river-estuary-ecosystem-classification*.

Inside:

[1] *Data newly collected or compiled for the ecosystem classification include land cover, land elevation, shallow-water bathymetry, agricultural ditches, wastewater treatment ponds, road fill, and general fill.*

[2] *Ecological metrics include the number, area, edge density, patch richness, and diversity of different ecosystems in the estuary, plus the distance and degree of connection between ecosystem patches.*

Key aspects of the classification

- ✓ **A complete study area.** The ecosystem classification covers the entire Columbia River estuary and its floodplain, from the mouth of the Columbia River to Bonneville Dam, 146 miles upstream. By analyzing the entire estuary, the classification supports comprehensive, informed study of the full continuum of estuarine ecosystems.
- ✓ **High-resolution GIS-based system.** All information in the classification is digital, which allows for easy quantification and analysis. The classification can quickly answer questions about how extensive different ecosystems are in the estuary, where they are located, and what important ecological attributes they display, such as shape, vegetation characteristics, and proximity to similar ecosystems.
- ✓ **Current, comprehensive data.** In creating the ecosystem classification, geologists and wetland scientists integrated the most current data available—in some cases compiling new data sets—to map features of interest. The resulting data and maps reflect current understanding of the dominant physical and biological characteristics of the estuary's ecosystems, and how they formed.
- ✓ **New vocabulary for better understanding**. The classification uses terminology that brings a new level of precision to discussion of the estuary's natural features. For example, the classification maps surge plains (which are formed by tidal flooding), tie channels (which connect floodplain lakes to the main river), and floodplain features such as backswamps, crevasse splays, and ridge and swale topography. By precisely defining and inventorying these features, the classification documents important formative processes that have not necessarily been described and measured before in the estuary.
- ✓ **Detailed narrative.** Creators of the ecosystem classification wrote in-depth descriptions of the natural and manmade features inventoried in the classification and notable occurrences in the estuary.[3]
- ✓ **Non-proprietary.** The classification's maps and data are non-proprietary, so they are available free of charge to anyone wanting to analyze the estuary for research, monitoring, resource management, or restoration planning. In addition, although the classification was developed specifically for the Columbia River estuary, its methods are comprehensive enough that they can be applied to other large, freshwater-dominated estuaries around the world.[4]

[3] *These narrative descriptions are as yet unpublished. For interim descriptions of ecosystem complexes and geomorphic catenae, contact Jim O'Connor of the U.S. Geological Survey* (oconnor@usgs.gov).

[4] *At the time of this writing, developers of the ecosystem classification were in the process of fully documenting their methods and results. For more information, contact the Lower Columbia Estuary Partnership. For interim descriptions, see U.S. Geological Survey Open File Report 2011-1228, Columbia River Estuary Ecosystem Classification—Concept and Application (C.A. Simenstad et al., 2011), available at* http://pubs.usgs.gov/of/2011/1228/.

LOCATION AND STUDY AREA. The approximate historical floodplain of the lower Columbia River defines the lateral extent of mapping for the classification. Lengthwise, the study area extends from the Pacific Ocean 146 miles upstream to Bonneville Dam.

National Agricultural Inventory Program (NAIP) (2009)

HIGH-RESOLUTION MAPPING. The classification turns aerial photos and other landscape data into high-resolution digital maps that show features as small as ¼ acre. This example illustrates the detail of land cover mapping around the Astoria airport, near Warrenton, Oregon.

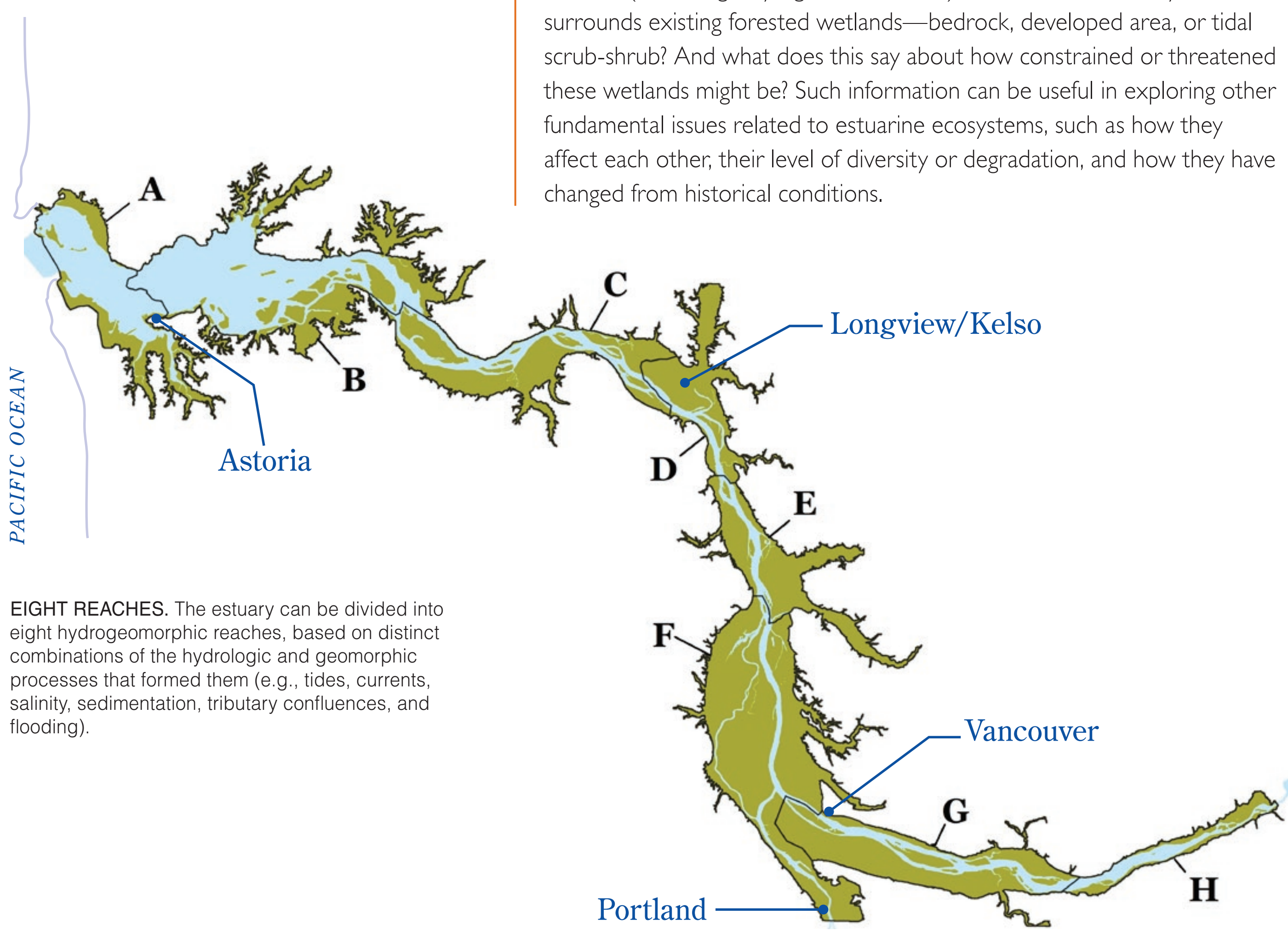
More about the Columbia River Ecosystem Classification[5]

> ▶ **KEY PHYSICAL PROCESSES IN THE ESTUARY**
>
> - *Tides*
> - *Floods and fluvial sediment transport*
> - *Wind-driven sediment transport*
> - *Landslides and debris flows*
> - *Late Holocene sea-level changes*
> - *Volcanism*
> - *Subduction zone earthquake cycle*
> - *Erosion*

Ecosystem classifications are tools for organizing information. They provide a framework for identifying the different components of complex natural systems and specifying the relationships among those components. In this, the Columbia River Ecosystem Classification is no different from other classifications. It identifies and maps the ecosystems in the Columbia River estuary, using an organizational structure that reflects the various geologic, hydrologic, and biological processes that drive the evolution of estuarine ecosystems.

An inventory of ecosystems

At one level, the classification is simply an inventory of the current ecosystems in the estuary. It tallies how many there are of each type, their size and shape, their location, and where they are situated in relationship to each other. How much surge plain has been isolated from tidal influence, and how much of this is being used for agriculture? How much tidal forested wetland (an ecologically significant habitat) remains in the estuary? What surrounds existing forested wetlands—bedrock, developed area, or tidal scrub-shrub? And what does this say about how constrained or threatened these wetlands might be? Such information can be useful in exploring other fundamental issues related to estuarine ecosystems, such as how they affect each other, their level of diversity or degradation, and how they have changed from historical conditions.



EIGHT REACHES. The estuary can be divided into eight hydrogeomorphic reaches, based on distinct combinations of the hydrologic and geomorphic processes that formed them (e.g., tides, currents, salinity, sedimentation, tributary confluences, and flooding).

[5] *Information in the following sections is based on data from the U.S. Geological Survey that was being prepared for publication at the time of this writing. For more information, contact the Lower Columbia Estuary Partnership.*

Understanding past, present, and future

Because the ecosystem classification defines features in terms of how they formed, it illuminates the past—and hints at the future. In a system as dynamic as the Columbia River estuary, it can be helpful to understand why and how an ecologically important feature developed, and therefore what its future might be. For example, what type of wetland is this, and how was it created? What do this subsided floodplain's origins and surrounding landforms suggest about its ecological trajectory, if it were reconnected to tidal influence?

The answers to these questions could determine whether a site is a good candidate for restoration (because of the processes taking place in and around it) and/or whether it should be protected (because it was formed by an infrequent geologic event and, if lost, would not be replaced for hundreds or even thousands of years).

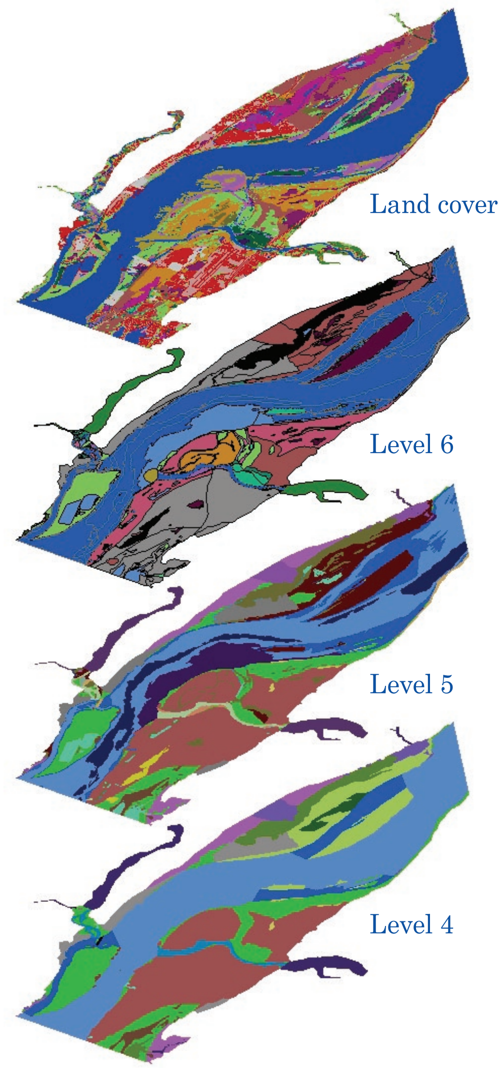
Structure and content of the classification

Structurally, the ecosystem classification combines diverse sets of physical and biological data to map ecosystems at six different hierarchical levels, depending on the time frame and spatial scale of relevant processes:

- **Levels 1 and 2: Ecosystem province and ecoregion**—These levels describe large regional features, such as the Cascade and Coast ranges, that were established by tectonic, volcanic, climatologic, and biologic processes operating over millions of years.[6]
- **Level 3: Hydrogeomorphic reach**—The estuary is divided into eight hydrogeomorphic reaches that are defined both by the broad-scale geologic environment and by more recent conditions and processes related to tides, currents, salinity, sedimentation, tributary confluences, and flooding. Each reach has its own unique character, owing to the particular processes and landforms that occur there.
- **Level 4: Ecosystem complex**—Ecosystem complexes are relatively large landforms that reflect the combined effects of massive disturbances (landslides, earthquakes, eruptions, large floods), shorter term processes (erosion, sedimentation, local flooding, vegetation succession, species extirpations), and human modifications to the landscape (diking and filling, channel hardening, and urban and suburban development). Examples of ecosystem complexes include terraces, floodplains, primary channels, dune fields, and volcanogenic deltas.
- **Level 5: Geomorphic catena**—Nested within the ecosystem complexes are geomorphic catenae, which are individual features or landforms, such as sand bars, natural levees, wetlands, floodplain channels, and lakes.
- **Level 6: Biocatena**—Biocatenae are geomorphic catenae categorized based on vegetative cover. They closely link biological characteristics with local geophysical processes and have names that are descriptive of specific ecosystems, such as "tidal coniferous wetland," "diked herbaceous wetland," "non-tidal scrub-shrub wetland," "agricultural tree farm," "agricultural," and "upland deciduous forest."

[6] *Levels 1 and 2 were adopted directly from existing continental-scale ecological classifications developed by the U.S. Environmental Protection Agency (i.e., EPA Ecoregion Levels II and III).*

MAPPING AT MULTIPLE HIERARCHICAL LEVELS. The classification organizes landscape features hierarchically, in both space and time. As one moves through the levels, the process time and resulting feature sizes generally decrease. Ecosystem complexes (Level 4) generally are large features that formed as a result of processes operating over thousands of years. Geomorphic catenae (Level 5) generally are smaller, having resulted from processes occurring over hundreds of years. Biocatenae (Level 6) incorporate land cover data (shown at the top of this figure) and reflect biological processes operating over decades, scores, or hundreds of years.



Certain biocatenae are of interest because they support unique local biodiversity, are used by species of importance (such as juvenile salmon), or represent rare habitat types. For example, the "tidal coniferous wetland" biocatena corresponds largely to Sitka spruce swamps in surge plains. This is an ecologically significant habitat type that is now rare in the estuary.

Levels 4, 5, and 6 of the classification represent newly mapped data, with the ecosystem complexes and geomorphic catenae being based on the most recent elevation data (including LiDAR topography and multibeam sonar bathymetry), wetland inventories, soils data, and aerial photographs, as well as other information. Geomorphic catenae and vegetative cover data taken from the Lower Columbia Estuary Partnership's 2010 Land Cover Classification served as the source data for the biocatenae.

The ecosystem classification also includes data on manmade features within the floodplain, such as dikes, deposits of dredged material, developed floodplain, and urban impervious area. Newly compiled data include the locations of agricultural ditches, wastewater treatment ponds, road fill, and general fill. Many of these human alterations are captured in a separate layer outside the classification hierarchy; others appear within the hierarchy as an ecosystem complex or geomorphic catena. Including manmade features in the classification acknowledges the human uses of the river corridor and allows the constraints on natural processes to be quantified, at both the local and landscape scales. This can aid resource managers and restoration practitioners in setting realistic goals for ecosystem recovery.

The ecosystem classification integrates all of these physical and biological data into one tool, where they are readily available for queries, cross-referencing, and analysis.

What are crevasse splays?

Crevasse splays are sandy deposits on the floodplain that have been left by flooding. They occur most commonly in large floodplain portions of the river where fluvial influences are strong, particularly in the late spring and early summer snowmelt period. Crevasse splays often have pairs of natural levees with a narrow channel between them, but they also occur as broad, sandy sheets and can have sandy, delta-like features. Grasses, shrubs, and trees—including oaks—often grow on the relatively well-drained natural levees of crevasse splays.

CREVASSE SPLAY. This crevasse splay formed from a floodplain channel that overtopped its banks, leaving sandy deposits at the floodplain interior. Riparian vegetation, including trees and shrubs, are present on the natural levees along the banks of the channel.

What are surge plains?

Surge plains are active tidal floodplains, consisting of vegetated flats that are flooded by the tides and then drained by extensive networks of branching tidal channels. Higher elevation surge plains typically support forest or scrub-shrub vegetation, while the more frequently inundated lower flooded surge plains support mostly herbaceous vegetation. Surge plains are found only in the lower portions of the river, where tidal influence is more pronounced (unlike the upper reaches, where fluvial forces dominate)

Si Simenstad, University of Washington

LOWER AND UPPER FLOODED SURGE PLAINS. An extensive network of tidal channels and emergent marsh has developed at lower elevations (lower flooded surge plain). At higher elevations (upper flooded surge plain), forested and shrub wetland vegetation dominate.

How can we use the classification?

The ecosystem classification organizes the Columbia River estuary—a complex, dynamic system—into elements that are relevant for decision making at different scales, from the site level to estuary-wide. For example, restoration practitioners might use the classification to help select and compare potential restoration, protection, or reference sites. For resource managers, the classification could inform reach-scale planning related to the effects of climate change or a future Cascadia subduction zone earthquake.

Although specific applications will vary, in general we expect to see scientists, planners, and resource managers using the classification to design robust status and trends monitoring programs, decide where to focus restoration and protection efforts, and incorporate quantification of the estuary's ecological constraints into management decision making.

Possible use: Understanding current conditions

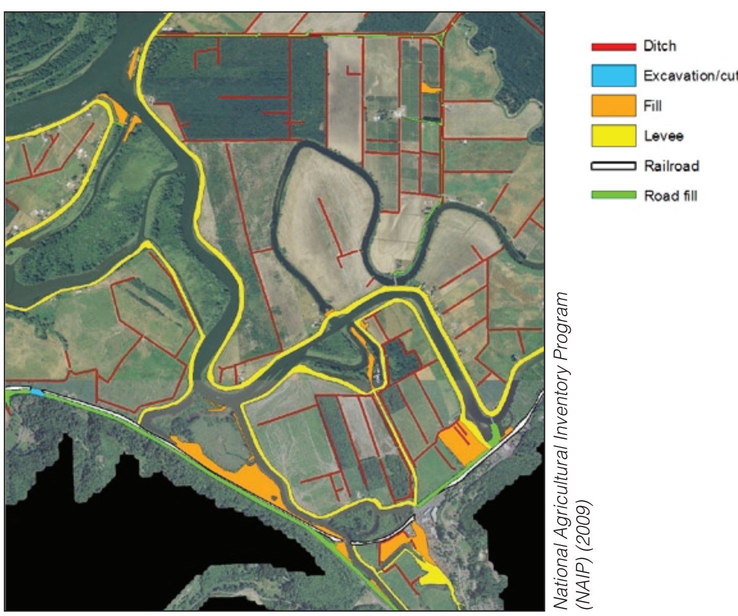
- *What ecosystems are present in the estuary, and where?*

The classification provides current information on the number, size, type, and spatial distribution of different landscape features and biocatenae, which in some cases are suitable surrogates for ecosystems of management interest, such as herbaceous and forested wetlands. Thus, the classification provides a comprehensive baseline inventory of key ecosystems in the estuary. With spatial information indicating where an ecosystem or habitat patch is located relative to other features, management decisions about that site can be informed by its proximity to stressors, such as dense road networks or urban or industrial land uses, or to desirable features, such as undisturbed areas or habitat that native plants could potentially colonize.

Thinking about species

For fish and wildlife species whose habitat is associated with particular ecosystem complexes, geomorphic catenae, or biocatenae, the classification's spatial data and ecological metrics may be useful in informing management decisions. For example, data on anthropogenic stressors and the distance between biocatena patches could influence where Columbia white-tailed deer are relocated or which areas are protected, to maximize habitat connectivity. Data on the location, size, and vegetative cover of dredge material disposal areas could aid in planning future disposals to encourage use by the ESA-listed streaked horned lark. And the ecological metrics for patches of tidal coniferous forest or intermittently exposed areas could help with the prioritization of salmonid habitat restoration projects. Over time, monitoring data will improve our understanding of how the ecosystem components delineated in the classification correlate to processes and habitats that species of management interest rely on.

MANMADE FEATURES. The ecosystem classification also maps anthropogenic features such as ditches, fill, levees, railroads, and roadways that constrain the estuary's natural processes. Quantifying such human uses of the river corridor can aid in planning restoration efforts and setting realistic goals for ecosystem recovery.



National Agricultural Inventory Program (NAIP) (2009)

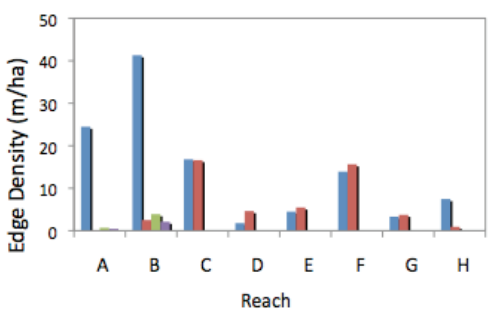
Throughout the estuary, natural or less disturbed areas exist close to more heavily modified ones.

Diked and tidal wetlands along Young's River (Reach A)

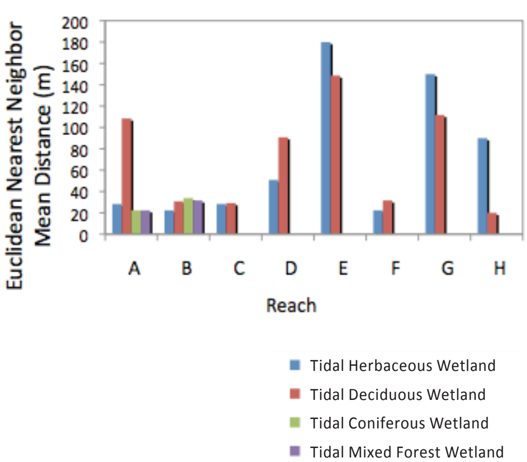
Scappoose Bay wetlands and industrial sites (Reach F)

SAMPLE ECOLOGICAL METRICS. Ecological metrics show generally high values for Reaches B, C, and F. For example, patches of tidal herbaceous wetland in Reaches A and B have high edge density (which suggests habitat complexity) and are relatively close together. Reach F has moderate values for edge density of tidal herbaceous and tidal deciduous wetland, and patches of these biocatenae are close together.

Edge Density Landscape Metric:



Aggregation (Euclidean Nearest Neighbor Distance) Landscape Metric:



For landscape features or biocatenae that are associated with fish and wildlife species of management interest, such as ESA-listed salmon, the ecosystem classification's spatial data are useful in understanding where there may be gaps in the chains of habitat that these species rely on for survival—and therefore where restoration or protection projects could be located to maintain a series of habitat stepping stones for those species.

Possible use: Assessing ecosystem function using ecological metrics

- *What are the ecological characteristics of individual habitat patches?*
- *Which areas are performing well?*

The ecosystem classification allows for quantification of ecological metrics related to the complexity and diversity of habitat patches, so that individual patches, areas, or even entire reaches can be characterized and compared. For example, for a biocatena of interest, the classification can be used to calculate how many patches there are of that biocatena, how big the patches are, and whether the patches have high or low edge density (i.e., whether their borders tend to be squiggly or smooth). Edge density is a measure of the length of interface between one ecosystem and another, and high edge density (meaning a squiggly border) suggests habitat complexity.[7] The ecosystem classification also can quantify how diverse the collection of patches is in a given area, whether similar patches tend to be clustered together or spread out, and whether similar patches are close enough together to be functionally connected.

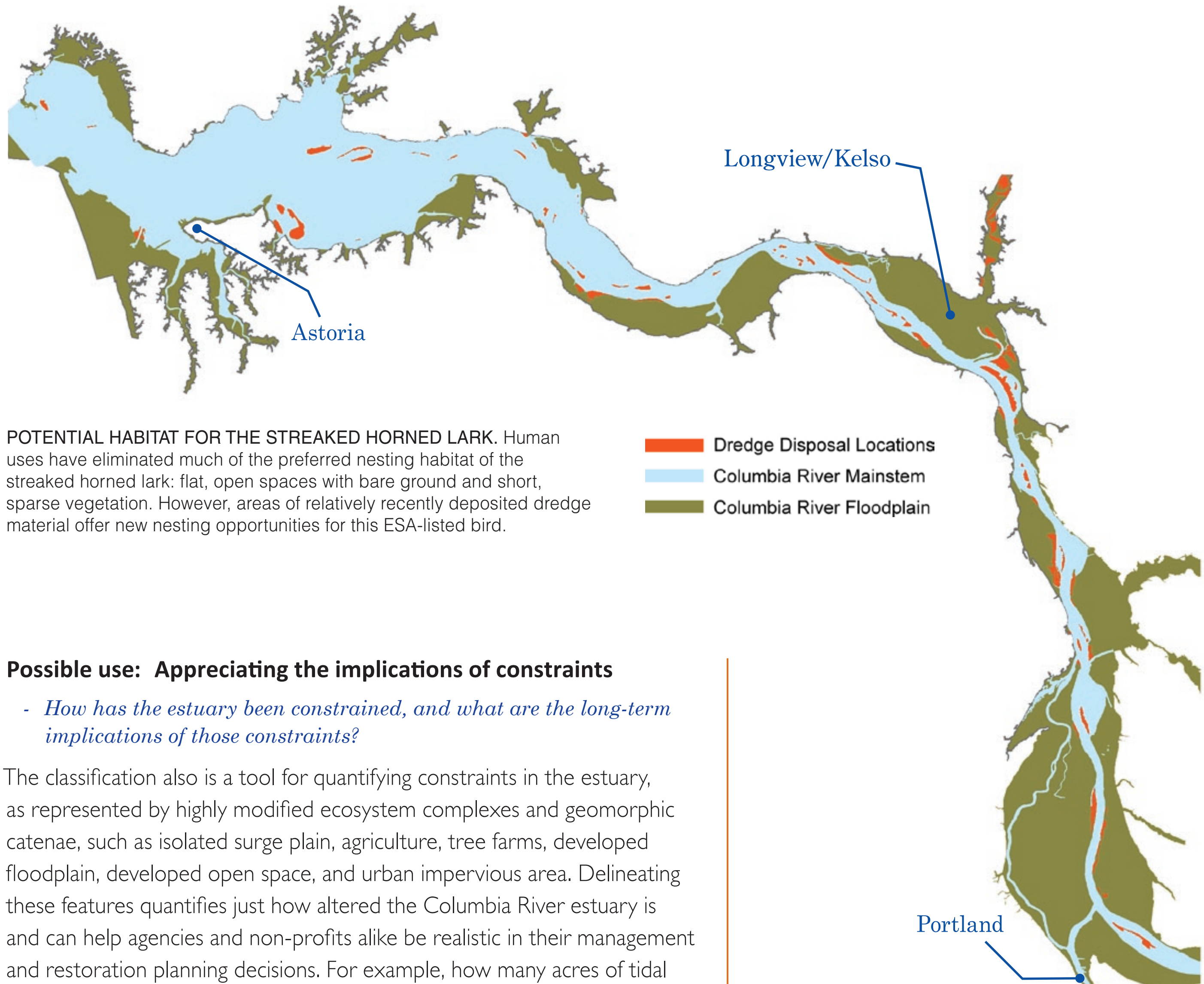
Ecological metrics provide a picture of how well an area is functioning. If an area is characterized by large habitat patches with metrics that suggest high complexity and diversity, it might have sites that are good candidates for protection. If the ecological metrics are lower but surrounding processes would support a well-functioning site, there might be opportunities for restoration. If the metrics show patches growing smaller and less connected over time, issues of habitat fragmentation may need to be addressed.

Possible use: Monitoring change over time

- *How are the estuary's ecosystems changing in response to natural processes and management actions?*

Because the ecosystem classification provides a standardized, repeatable method of delineating ecosystem components and calculating ecological metrics, it is ideal for assessing change in ecosystems over time. We expect the classification to be particularly useful for siting monitoring locations, especially when specific biocatenae correlate well to fish and wildlife species of interest. In these cases, the classification can be helpful in situating sampling sites within the same ecosystem complex or geomorphic catena, so that site locations truly are comparable.

[7] *High edge density is related to ecosystem functions such as sediment retention, nutrient cycling, and exchange of materials that often are more intense at the edges of habitat patches than inside patches.*



POTENTIAL HABITAT FOR THE STREAKED HORNED LARK. Human uses have eliminated much of the preferred nesting habitat of the streaked horned lark: flat, open spaces with bare ground and short, sparse vegetation. However, areas of relatively recently deposited dredge material offer new nesting opportunities for this ESA-listed bird.

Possible use: Appreciating the implications of constraints

- *How has the estuary been constrained, and what are the long-term implications of those constraints?*

The classification also is a tool for quantifying constraints in the estuary, as represented by highly modified ecosystem complexes and geomorphic catenae, such as isolated surge plain, agriculture, tree farms, developed floodplain, developed open space, and urban impervious area. Delineating these features quantifies just how altered the Columbia River estuary is and can help agencies and non-profits alike be realistic in their management and restoration planning decisions. For example, how many acres of tidal coniferous forest actually can be restored, within a particular area and in the estuary as a whole? If this number is small, what compensatory measures can be taken? In some cases, quantifying constraints may underscore the need for bold action in areas where there still is a range of available management options.

By linking manmade features with natural processes (many of which are changing,) the ecosystem classification offers a way to analyze the likely developmental trajectory of important ecosystems in the estuary. Which ecologically valuable complexes and catenae are currently being created only slowly, if at all? Which are most vulnerable to major natural disturbances? Which are at risk from gradual, ongoing change? As a tool for understanding how estuarine ecosystems form, change, and possibly disappear, the classification supports strategic decision making about how best to maintain the estuary's vitality and resilience over the long term, even given the system's many constraints.

David Leonard, U.S. Fish and Wildlife Service

MALE STREAKED HORNED LARK

What is the classification telling us so far?

Initial findings from the classification provide important information about current conditions, particularly with respect to ecosystem diversity, habitat loss, and ecological function. This information can be used to frame additional inquiries, predict the future trajectory of key estuarine ecosystems, and understand long-term opportunities and risks. The following text summarizes general findings.

▶ The diversity of ecosystems is moderate throughout the estuary, but certain important ecosystems are found in only a few reaches.

The classification provides extensive data on the number, area, and distribution of ecosystem complexes, geomorphic catenae, and biocatenae. From this, the degree of diversity in the landscape can be calculated—i.e., are there many different types of features within a particular area or reach, or just a few? Are some reaches significantly more diverse than others? The data indicate relatively little variation in the diversity of ecosystem complexes in the estuary as a whole. This means that the degree of diversity is roughly the same throughout reaches. In addition, it is at a moderate level.[8] However, each reach has its own unique character, based on the dominant processes that occur within it.

The classification shows relatively strong correlations between complexes or catenae and specific reaches.[9]

Much of the:	occurs in:
Dune deposit	Reaches A and H[10]
Permanently flooded area	Reach B
Wetland	Reaches B and C
Coniferous land cover[11]	Reaches A through C
Surge plain (isolated and non)	Reaches A through D
Floodplain	Reaches D through H
Natural levee	Reaches D through H
Lake bed	Reaches D through H (especially Reach F)
Tie channel	Reach F
Developed floodplain	Reaches F and G
Tributary fan	Reach H
Landslide deposit	Reach H

▶ More than half of the current land area in the estuary represents aquatic or terrestrial habitat that has been converted to human uses.

By quantifying the occurrences of complexes, catenae, and biocatenae, the classification confirms the high degree of human modification of the estuary, providing detailed information on the extent, type, and location of habitat losses, both aquatic and terrestrial. Particularly noteworthy is the extent of diking, filling, or other conversion of land and water for human uses. Of all the land area mapped for the classification,[12] 64 percent has been diked, converted to agriculture, or developed. These human activities don't just directly eliminate habitat for fish and wildlife species—they also reduce the total area in the estuary where hydrologic processes can create and maintain future habitat.

Meet the streaked horned lark

The streaked horned lark (Eremophila alpestris strigata) is a small, ground-nesting bird that likes wide-open spaces. Ideal habitat for this Pacific Northwest native is a flat, treeless expanse with short, sparse vegetation, where the lark can access bare ground. Much of the lowland prairie, sandy floodplain, and similar habitat this subspecies historically used has been lost. Nowadays, the streaked horned lark often nests in open spaces at airports (in Portland and Corvallis) and on relatively recent dredge deposits in the estuary. In 2013, the streaked horned lark was listed as threatened under the Endangered Species Act.

8 *Between 2.1 and 2.3 on the Shannon-Wiener diversity index, which has a scale of 0 (low) to 4 (high).*

9 *Correlations indicate that a relatively large percentage of the total area of a feature occurs within the reaches indicated.*

10 *For a map of hydrogeomorphic reaches in the estuary, see p. 3.*

11 *This includes all biocatenae that have coniferous forested areas, which are found only in Reaches A through C. Calculations were based on land area only, excluding large, open-water areas.*

12 *Mapped land area represents 56 percent of the entire area of the estuary and excludes areas designated as deep channel, permanently flooded, intermittently exposed, unknown depth, and artificial water body.*

Specific findings related to the occurrence, area, and distribution of human-impacted complexes and catenae include the following:

- Agriculture is the most extensive of all the biocatenae (in terms of area), followed by developed urban impervious.
- Together, diked, agricultural, and developed biocatenae make up 64 percent of all the biocatenae mapped in the estuary (in terms of area) and represent more than half of the total area in each reach, except in Reaches B and H. Reach C has the highest percentage (73 percent) of diked, agricultural, and developed biocatenae.
- There is more isolated surge plain and floodplain in the estuary than tidally connected surge plain and floodplain.
- A total of 57 percent of the area of floodplain complexes in the estuary has been wholly or partially isolated from the river by levees, roadways, and railroad fill. Twenty-five percent consists of developed floodplain.
- Most developed floodplain is in Reaches D, F, and G, where fill has been used to create new land, primarily for industrial uses in Longview, Vancouver, and Portland.

The classification data also show that complexes and catenae occur mostly in many small patches. When compared with historical data, which show much larger patches, this may be indicative of habitat fragmentation in the estuary.

▶ The highest functioning patches of tidal wetlands (both forested and herbaceous) are in Reaches B, C, and F.

Ecologically, how well are individual habitat patches functioning? To answer this question, developers of the ecosystem classification analyzed patches of tidal forested and tidal herbaceous wetlands. (These biocatenae correspond to ecosystems of particular value to fish and wildlife.) For each patch, the scientists calculated edge density (an indicator of habitat complexity), connectance (which indicates whether individual patches are functionally connected), and aggregation (to understand whether patches are clustered in a way that helps fish and wildlife migrate and disperse). Reaches B, C, and F had the highest values, reflecting the highest ecological function. The patches in Reaches A, G, and H also had relatively high values—especially the forested wetlands in Reach A. In contrast, Reaches D and E generally had lower values, as well as fewer occurrences of these biocatenae.

Although these results are presented at the relatively coarse reach scale, similar analyses can be performed at finer scales to help characterize conditions at the site level.

LANDSCAPE METRICS ANALYSIS OF ECOLOGICALLY IMPORTANT BIOCATENAE

(Tidal Coniferous, Deciduous, Herbaceous, and Mixed Forest Wetlands)

Metrics analyzed were edge density, aggregation, and connectance. High values indicate high ecological value.

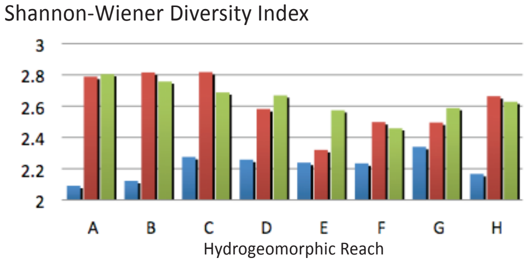
Reaches	Landscape Metrics Values
B, C, F	Consistently high
A, G, H	High
D and E	Relatively low

COMPLEXES AND CATENAE WHOSE FORMATION HAS LARGELY BEEN DISRUPTED

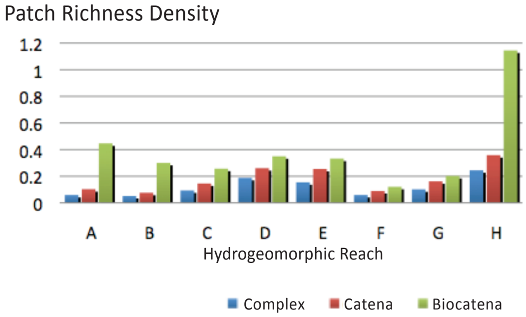
▪	Dunes
▪	Floodplains
▪	Floodplain backswamps
▪	Natural levees
▪	Floodplain ridge and swale
▪	Crevasse splays

DIVERSITY INDICES. The ecosystem classification supports analyses of the landscape's capacity to maintain discrete populations of fish, wildlife, and plants. The high patch richness value for Reach H biocatenae is likely a result of the confined geometry of that reach, where many types of landforms are squeezed into a narrow valley bottom and channel area.

Shannon-Wiener Diversity Index



Patch Richness Density



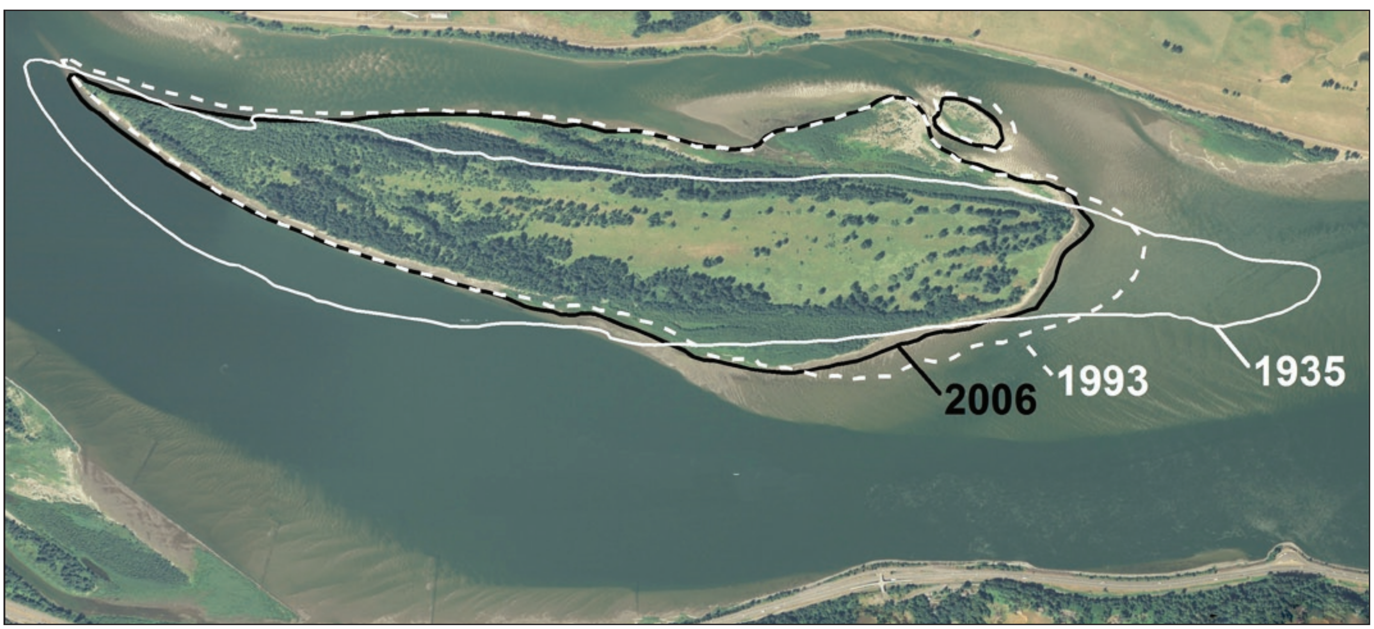
A tool for considering the estuary's future

> ▶ **Flow, sediment, and subsidence**
> *Isolated surge plains illustrate some of the effects of floodplain disconnection. Cut off from daily tidal influence by levees and from other fluvial inputs of sediment (because of reduced spring freshets and sediment loads), isolated surge plains receive much less sediment than do tidally connected surge plains. The isolated surge plains tend to subside. In some cases they are as much as 1 meter lower than nearby connected surge plains. Subsidence changes vegetation patterns in the surge plain, fish and wildlife use, and possibly the site's potential for recovery if restoration is attempted.*

Human activities have altered the estuary's natural ecosystems directly, but there have been important indirect effects as well, including hydropower-related reductions in peak flows and sediment input, both of which are needed for the formation and maintenance of several landforms identified in the classification, such as natural levees and crevasse splays. Without regular flooding and sediment inputs, development of these and similar features slows, and new features may not form. Although the effects of reduced peak flow and sediment transport have been well documented before now,[13] the classification provides unique insight into where impacts are most pronounced, which ecosystems are the most vulnerable, where the impacts might be minimized through various management actions, and how ecosystems might respond in the future if these effects become more or less severe.

With natural processes changing, decisions about the estuary's protection, restoration, and management take on added significance, and a long-range, strategic view is even more important. The Columbia River Ecosystem Classification is a tool for taking such a view—for analyzing current conditions, identifying risks, and finding ways to help maintain the estuary's vitality over the long term, even as individual ecosystems form, change, and possibly disappear.

Reed Island: National Agricultural Inventory Program (2009)



LANDSCAPE CHANGE THROUGH EROSION AND SEDIMENT DEPOSITION. Significant portions of Reed Island (in Reach G) have eroded away since 1935 as a result of the combined forces of erosion and fluvial sediment transport and deposition. At the same time, new areas of the island have formed along its northern shore.

[13] *For example, the impacts of changes in flow are documented in reports such as Salmon at River's End: The Role of the Estuary in the Decline and Recovery of Columbia River Salmon (D.L. Bottom, C.A. Simenstad, J. Burke, A.M. Baptista, D.A. Jay, K.K. Jones, E. Casillas, and M.H. Schiewe, 2005, U.S. Dept. Commer., NOAA Tech. Memo NMFS-NWFSC-68, 246 p.).*

COMPLEXES		CATENAE	
Channel & Backwater Types			
primary channel	main channel of the Columbia River	deep channel	deepest part of the channel
secondary channel	channel that connects to the primary channel of the mainstem Columbia River at both ends, at least seasonally	permanently flooded	channel or backwater areas that, in elevation, are between deep channels and intermittently exposed areas
backwater embayment	inundated area that connects to main channels but is not channelized (e.g., Scappoose Bay)	intermittently exposed	sparsely vegetated beaches and shallow-water areas within channels
tributary channel	main channel of the major tributaries entering the Columbia River	side channel	narrow channels that flow around islands, on major tributaries
tributary secondary channel	Multnomah Channel	channel bar	seasonally exposed channel deposits with little to no vegetation
		tributary delta	intermittently exposed deposits from tributary streams
		channel bedrock	intermittently exposed bedrock within channels
		artificial waterbody	fish ladders, navigation ponds, wastewater treatment ponds
		unknown depth	channel areas for which bathymetric data are not available
Surge Plain Types			
surge plain	active tidal floodplain, typically consisting of vegetated flats drained by a network of tidal channels	lower flooded surge plain	active surge plains that are below mean higher high water and inundated regularly by the tides
isolated surge plain	surge plain that has been disconnected from tidal influence	upper flooded surge plain	active surge plains that are above mean higher high water and therefore inundated less often than daily
		undifferentiated surge plain	floodplain whose elevation (i.e., upper or lower) has not been determined
		tidal channel	sloughs
		permanently flooded tertiary channel	shallow parts of narrow channels in surge plains, connected to other channels at both ends
		intermittently exposed tertiary channel	tertiary channels (as above) that have areas of exposed sediment
Floodplain Types			
floodplain	undifferentiated Holocene floodplain	floodplain	undifferentiated floodplain
floodplain backswamp	low area away from the primary channel, generally with many wetlands and lakes (historically or currently)	natural levee	alluvial ridges along historical or current channels
floodplain ridge and swale	sets of parallel, gently curved natural levees alternating with swales	lake bed	areas where historical lakes have been drained
crevasse splay	pair of natural levees with a narrow channel between them	floodplain channel	channels that do not originate outside the floodplain and are not connected to a primary or tributary channel at both ends
tributary fan	alluvial fan at the mouth of a tributary	tie channel	channels that connect floodplain lakes to the main river channel
tributary floodplain	floodplain of a tributary valley	tributary fan	alluvial fan at the mouth of a tributary
		tributary valley (outside floodplain)	parts of tributary valley bottoms that were not mapped in detail
		minor tributary	small channels that originate outside the floodplain
		wetland	flat or concave areas that are or were saturated for part of the year and are not significantly influenced by tides
		lake/pond	non-channelized bodies of water
		unknown	area that could not be defined as a geomorphic catena
Non-fluvial, Relict, or Prehistoric Types			
bedrock	bedrock above the surface of the floodplain	bedrock	bedrock above the surface of the floodplain
dune	wind-formed ridges and hills of sand and silt	dune	wind-formed ridges and hills of sand and silt
volcanic delta	volcanic debris at the mouth of a river	volcanogenic delta	volcanic debris at the mouth of a river
terrace	relict alluvial deposits that formed from prehistoric flow	terrace	relict alluvial deposits that formed from prehistoric flow
landslide	deposits formed by mass movement down slopes	landslide deposit	deposits formed by mass movement down slopes
outburst flood deposit	material deposited as a result of the natural breaching of the Bonneville landslide, in 1425-1450 A.D.		
Anthropogenic Types			
developed floodplain	area where the original floodplain has been mostly obscured by development	artificial beach/bar	bare area along a channel that is not regularly inundated
dredge disposal area	area where material dredged from the river channel has been deposited	dredge disposal area	area where material dredged from the river channel has been deposited
		filled area	area that formerly was water but has been purposely filled
		developed floodplain	area where the original floodplain has been mostly obscured by development

Features of special interest

The classification maps 21 different ecosystem complexes, 35 geomorphic catenae, and 40 biocatenae. The complexes and catenae described below are of particular interest because of the role they play in the ecology and management of the Columbia River estuary.

Intermittently exposed

Si Simenstad, University of Washington

Intermittently exposed areas are beaches, sand bars, mud flats, and other shoreline areas that alternate between inundation and exposure, as a result of tidal or seasonal changes in water flow. Intermittently exposed areas consist of silt, clay, and sand that have been transported from upstream (either suspended in river water or as bedload) or disposed of as part of the dredging of the Columbia River navigation channel. Typically, intermittently exposed areas have little to no vegetation, but where they adjoin natural floodplains or surge plains they serve as ecologically important transition zones to areas of emergent and woody vegetation. Mudflats commonly contain organic material and contribute significantly to nutrient cycling: both mud and sand flats produce benthic algae that support insects and amphipods eaten by juvenile salmon, white sturgeon, flounder, and various shorebirds.

Intermittently exposed areas are sensitive to changes in sea level, river stage, tidal conditions, waves, and wake size and frequency; thus they are vulnerable to erosion.

Surge plains

Si Simenstad, University of Washington

Surge plains are vegetated flats that are flooded by the tides and then drained by extensive networks of branching tidal channels. It is likely that much of the surge plain area in the estuary developed from tidal flats. Surge plains form through (1) the accretion of clay, silt, and fine sand that are delivered from mainstem rivers and adjacent tidal flats, and (2) the accumulation of organic matter that is produced in situ; this commonly results in peaty and organic-rich soils. Under stable sea level conditions young surge plains grow vertically quite quickly, but their pace slows as they age and gain elevation.

Because of the feedback processes involving sedimentation, organic material production, and surface elevation, surge plains can be resilient to sea level changes, particularly if there is adequate sediment input. However, wave erosion can eat away at surge plains from the side. Additionally, many surge plains in the estuary have been lost or altered as a result of human impacts. There also is evidence of forested surge plains suddenly down-dropping to lower in the intertidal zone as a result of great Cascadia subduction zone earthquakes, including the most recent one in A.D. 1700. Interestingly, some of the down-dropped surge plains were growing Sitka spruce forests again within about 100 years.[14]

The ecosystem classification identifies upper flooded and lower flooded surge plains. Upper flooded surge plains are tidal wetlands that are mostly above mean higher high water[15] (MHHW). Upper flooded surge plains that

[14] *Benson, B.E., B.F. Atwater, D.K. Yamaguchi, L.J. Amidon, S.L. Brown, and R.C. Lewis. 2001. Renewal of tidal forests in Washington State after a subduction earthquake in A.D. 1700, Quaternary Research. Volume 56, Issue 2, September 2001, pages 139-147, ISSN 0033-5894, http://dx.doi.org/10.1006/qres.2001.2251.*

[15] *Mean higher high water is the average height of higher high water during a tidal day, averaged over 19 years.*

have never been diked support scrub-shrub or forest vegetation, including once common spruce-forested wetlands, and typically have substantially more microtopography than diked surge plains do—probably because of the abundance of snags, stumps, and large woody debris.

Lower flooded surge plains are tidal wetlands that are mostly below MHHW. They generally have a denser network of tidal channels than upper flooded surge plains do and are inundated more frequently; thus they support primarily herbaceous vegetation, rather than scrub-shrub or tidal forest.

Most surge plains (of both types) are found in Reach B.

Isolated surge plains

Isolated surge plains are former surge plains that have been completely or partially blocked from tidal influence, typically by dikes and levees. Isolated surge plains account for 67 percent of the surge plain area in the estuary and 10 percent of the entire classification study area. Isolated surge plains typically are flat and are used for agricultural production or as pasture. Many of former tidal channels in surge plains have been filled or isolated by tide gates. Once a surge plain has been isolated from tidal inundation and material transfers (e.g., sediment, vegetative matter, and large woody debris), lateral erosion and vertical buildup of the soil tend to stop, or to slow substantially. The surface then subsides as organic matter in the soil is oxidized; the subsidence sometimes is compounded by physical compaction (from vehicles and animals) and surface erosion. In the Columbia River estuary, the elevation of isolated surge plains averages 0.9 meter below that of non-isolated surge plains. However, when isolated surge plains are reconnected so that they are subject to repeated tidal inundation, renewed buildup of the soil surface can be speedy—up to 2.4 centimeters per year.[16] This finding is consistent with the rapid accretion and reestablishment of tidal forests following the episodic subsidence caused by Cascadia subduction zone earthquakes.

Surge plain isolation has reduced the extent, frequency, and duration of overbank flooding from tides and river flow, and thus the amount of shallow-water habitat. One study in Reach B showed 60 percent less shallow-water habitat available today during the spring freshet than in the period before flow regulation, when there were few or no levees.[17]

Tidal channels

Si Simenstad, University of Washington

Tidal channels are waterways where flow is affected by the tide. Typically tidal channels drain surge plains, often in dense networks with many winding, branching channels; this is particularly true in lower flooded surge plains. In many surge plains, the network of tidal channels is so dense that it effectively links the surge plain with the main channel, enabling exchanges of water, sediment, nutrients, organic detritus, and aquatic organisms.

It is likely that tidal channels developed from predecessor channels in sand and mud flats. Today's tidal channels are relatively stable, in that they do not migrate much, but their width, depth, and velocity vary based on flow conditions, channel length, and drainage area. Pool spacing is determined largely by wood jams. In forested wetlands, beaver dams and lodges historically influenced the size and shape of tidal channels.

Tidal channels have been affected by loss of beaver, reduced large wood input, and dikes and levees that isolate channels from the main

[16] *Diefenderfer, H.L., A.M. Coleman , A.B. Borde, and I.A. Sinks. 2008. Hydraulic geometry and microtopography of tidal freshwater forested wetlands and implications for restoration, Columbia River, U.S.A. Ecohydrology & Hydrobiology, Volume 8, Issues 2–4, 2008, pages 339–361.*

[17] *Kukulka, T., and D.A. Jay. 2003. Impacts of Columbia River discharge on salmonid habitat—1. A nonstationary fluvial tide model. Journal of Geophysical Research, Volume 108, No. C9, 3294, doi:10.1029/2003JC001829, accessed July 5, 2011, at http://onlinelibrary.wiley.com/doi/10.1029/2002JC001382/abstract.*

body of the estuary. Currently, the total area of blocked tidal channels in the estuary exceeds that of connected channels. For tidal channels that do remain connected, changes in flow and sediment regimes have altered water and sediment fluxes, possibly with significant ecological consequences.

Floodplain backswamps

Keith Marcoe, LCEP

Floodplain backswamps are poorly drained, low-lying areas away from the main channel and separated from it by high terrain, such as natural levees. Backswamps generally have many wetlands, ponds, and active lakes (e.g., Vancouver and Sturgeon lakes), as well as drained lake beds. Although backswamps today are found mostly in Reach F, they are the most extensive of all the floodplain-type ecosystem complexes and historically were widespread between the Lewis and Sandy rivers and along the lower Willamette.

Backswamps are the result of differential sedimentation rates. During floods, suspended sediment tends to settle out at channel margins, forming natural levees and splays. By the time flow moves away from the channel edge, it already has dropped most of its sediment, so sedimentation rates are lower in the middle and far edges of the floodplain area than they are at the channel's edge. Over time, the disparity in elevations grows, which further amplifies the different sedimentation rates. Sometimes the floodplain depressions become low enough to intercept the groundwater table, resulting in large but shallow floodplain lakes.

Flow regulation and reduced sediment loads have slowed the processes that create floodplain backswamps. Water bodies in backswamps are affected by drainage, sea-level rise, river level, and other factors that influence water levels.

Floodplain ridge and swale

Si Simenstad, University of Washington

Floodplain ridge and swale topography consists of sets of gently curved natural levees alternating with lower lying swales. It is likely that most ridge and swale topography in the estuary was created through lateral migration of the Columbia River mainstem over several millennia. The formation process is similar to that of floodplain backswamps, where differential sedimentation rates lead to a disparity in elevation with distance from the main channel. However, in the case of ridge and swale topography, the added effect of channel migration, in addition to high rates of lateral sediment accretion, has resulted in the alternating pattern of high and low features. Typically these occur in crescent-shaped sets parallel to the Columbia River. The ridges tend to support willow, cottonwood, and other woody vegetation, while the swales have mostly herbaceous and wetland species.

Ridge and swale accounts for one-quarter of the floodplain area in the estuary and is most common in Reaches D through G (especially in Reach F). Formation of ridge and swale topography has essentially stopped, as a result of human effects such as levee construction and reductions in annual flooding and sediment transport. Existing ridges and swales likely will remain static except where they are directly modified by humans.

Natural levees

Si Simenstad, University of Washington

Natural levees are long, narrow, curved ridges, located along historical or current channels, that typically have elevations of 4 to 10 meters (relative to NAVD88).[18] Natural levees form during floods, when the river or stream deposits coarse sediment at the edge of the channel, or when flooding breaches an existing natural levee and delivers sediment to the floodplain behind it. About half of all the area of natural levees in the estuary consists of the "ridges" in floodplain ridge and swale topography. Many of these are in Reach F, between the Willamette and Lewis River confluences.

Natural levees have sandier, better drained soils than most other floodplain features and support a variety of grasses, shrubs, and trees (including oaks) that are different from the vegetation in the lower elevations of the floodplain. Historically, natural levees were the site of several major Native American villages along the lower Columbia River, especially in Reaches F and G. The historical village of Cathlapotle in Reach F, which was occupied from about A.D. 1450 to 1835, is one example. Currently, 77 percent of the area of natural levee that is part of floodplain ridge and swale topography is used for agriculture or has been developed for other purposes.

Channel stabilization and reduced flooding and sediment transport have mostly halted the formation of natural levees in the estuary. Today, only about 7 percent of natural levees in the estuary are inundated by the median peak flow.

Tie channels

Tie channels are perennial waterways that connect floodplain lakes to the main river channel. Narrow and sinuous, tie channels commonly are flanked on both sides by natural levees, which tend to grow with time. Although tie channels do lengthen as the main channel moves away from the backswamp area, they seldom migrate laterally, and many of them appear to be quite long-lasting. However, their stability, longevity, and general morphology are not well understood. For example, it is unclear why tie channels do not eventually fill with sediment and become plugged. Tie channels are most common in Reaches F and G, where they are associated with crevasse splays.

Tie channels are important to the evolution of backswamp lakes and wetlands because they act as a conduit for water, silt, fine sand, and aquatic life. They also play an important role in maintaining the water quality and temperature of floodplain lakes and backswamps.

Crevasse splay

Crevasse splays are sandy deposits on the floodplain that have been left by flooding. They are commonly associated with tie channels, which connect the main river with floodplain lakes in backswamps, but they also can be broad and slightly higher areas of sand deposition near the main channel. When flanking tie channels, crevasse splays consist of a pair of natural levees with a narrow channel between them. Also like tie channels they tend to be stable, existing sometimes for hundreds of years. Crevasse splays associated with tie channels often end in a sandy, delta-like feature within lake basins. In the Columbia River estuary, most crevasse splays occur in Reach F (e.g., on Sauvie Island) and are associated with areas of floodplain backswamp. Crevasse splays result from the concentrated transport of sediment and water into the floodplain, either currently or historically. Although crevasse splays can form in different ways, a classic pattern is for sediment-laden water to burst through a natural levee during flooding, create a set of interwoven channels that splay out into the floodplain, and deposit sediment along the margins of the largest channel within that splay, thus building two parallel natural levees over time. As flow and sediment deposition continue, the crevasse splay lengthens, extending out into the floodplain.

[18] *National Geodetic Vertical Datum of 1988, a standard vertical datum used in surveying.*

Many crevasse splays now are no longer forming because they are no longer connected to active tie channels. Although disconnection can occur as the result of natural floodplain evolution, nearly two-thirds of the crevasse splay area in the estuary is isolated from major channels because of levees, dikes, or road fill.

Filled area

In the ecosystem classification, filled areas consist of historical primary or secondary river channel, intermittently exposed areas, floodplain, or surge plains that have been filled in for human uses, such as urban and industrial development, roadways, or levee construction. Most filled area is considered part of developed floodplain and consists of urban impervious surfaces.

Filled areas are widespread. Many of them occur in Reaches A and B, particularly at Astoria and Tongue Point. Most of Astoria along the Columbia River was filled in after large fires in 1883 and 1922 destroyed much of the city, which had been built largely on wooden pilings over the water. The developed area near Tongue Point was filled in in 1921 and the 1940s to facilitate construction of U.S. Naval facilities. In Reach H, a large filled area near Bonneville Dam connects Hamilton Island to the mainland.

Dredge disposal areas

Keith Marcoe, LCEP

Dredge disposal areas are placement sites for sediments removed from channels, mostly to maintain a navigation channel. During the last century, removal rates from the Columbia and lower Willamette rivers have been relatively constant, at approximately 850,000 cubic meters per year.[19] The exception to this was after the 1980 Mount St. Helens eruption, when substantial additional dredging was needed to remove volcanic debris from the Cowlitz River drainage. In fact, almost 30 percent of the area mapped as dredge disposal sites is in Reach D along the Cowlitz River and on the Columbia River between the Kalama and Cowlitz confluences.

Every reach has dredge disposal areas, with the amount generally increasing as one goes upstream; however, the largest individual site is in Reach D. Most dredge disposal areas are located near the primary channel, on or adjacent to the floodplain. More than half of the area of dredge disposal sites represents newly created land that did not exist before the original topographical field surveys of the estuary, between 1868 and 1901. The newly created land includes many islands, especially in Reach B (e.g., Mott, Lois, and Rice islands and Miller Sands).

Dredge disposal areas commonly have a higher maximum elevation than their neighboring floodplain landforms and in many places are above the 1894 flood stage. In these locations they mostly support upland vegetation. However, through exposure to flow and wind, sand from dredge disposal areas sometimes is reincorporated into hydrologic and sediment processes and reworked to create new floodplain or other landforms. Thus, dredge disposal areas tend to be dynamic, with many different forms, elevations, and vegetative cover types, including some natural biocatenae. Whether dredge disposal areas over time can form ecosystems comparable to those created through natural sediment accretion and erosion processes is a topic of management interest, and tracking the succession of dredge disposal areas may guide their future placement in the estuary.

[19] *Templeton, J. W., and D.A. Jay. 2012. Lower Columbia River sand supply and removal: estimates of two sand budget components. J. Waterway, Port, Coastal, Ocean Eng., 139(5) p. 383-392.*

Level 4: Ecosystem complexes, broken down by reach

Note: Areas in hectares (ha)		Reach								Estuary
Category	Complex	A	B	C	D	E	F	G	H	Total
Channel and Backwater	Primary Channel	12628.0	21133.3	4062.5	1381.2	1927.7	2553.3	4129.2	3026.3	50841.4
	Secondary Channel		2468.3	2076.0	239.8	263.3	84.8	1380.5	309.2	6822.0
	Backwater Embayment	6.2	34.4	156.3	74.0	31.5	287.5	47.8		637.7
	Tributary Channel	1964.2	522.4	117.5	496.7	272.3	1846.3	83.1	2.0	5304.4
	Trib. Secondary Channel						830.4			830.4
Surge Plain	Surge Plain	850.4	5549.4	1779.3						8179.1
	Isolated Surge Plain	4897.7	4002.4	6962.0	579.1					16441.2
Floodplain	Floodplain	246.4	820.4	759.9	1191.1	933.0	2680.7	2644.1	540.7	9816.3
	Floodplain Backswamp		110.8	709.7	336.8	389.9	8844.7	1800.7	53.9	12246.4
	Floodplain Ridge and Swale		158.3	818.3	358.2	1589.0	4002.4	1542.8	108.8	8577.8
	Crevasse Splay		5.0	270.7	67.2	59.5	2378.9	188.9	12.0	2982.2
	Tributary Fan	66.0	249.0	271.3	96.3	86.9	297.4	102.3	832.1	2001.3
	Tributary Floodplain	309.3	941.4	41.5	307.1	1544.9	620.3	419.9	93.0	4277.4
	Unknown	13.4	2.2	4.1	0.4	23.3	11.7	2.9	20.1	78.2
Non-fluvial, Relict or Prehistoric	Bedrock	42.0	41.6	128.3	215.9	0.8	237.6	72.9	6.9	745.9
	Dune	3555.0	0.1				1214.9	12.7	77.5	4860.2
	Volcanogenic Delta				1615.1	3184.4		1100.1		5899.6
	Terrace	57.3	22.2	25.9	3.6	53.3	1075.6	817.8		2055.7
	Landslide	0.5	44.0	129.0	0.3	20.2	5.3		448.8	648.2
	Outburst Flood Deposits								391.3	391.3
Anthropogenic	Developed Floodplain	516.9	150.7	319.5	1719.6	191.6	2980.8	2119.7	208.7	8207.3
	Dredge Disposal Area	87.5	550.3	584.0	901.2	411.6	338.5	223.9		3097.1

There is considerably more isolated surge plain in the estuary than connected surge plain.
The high amount of isolated surge plain in Reach C could represent opportunities for restoration and floodplain reconnection.

Much of the estuary's floodplain backswamp occurs in Reach F, which has high amounts of associated features, such as floodplain ridge and swale and crevasse splays.

Reaches D, F, and G have high amounts of developed floodplain (compared to other reaches).

Level 5: Geomorphic catenae, broken down by reach

Note: Areas in hectares (ha)	Reach								Estuary
Geomorphic Catena	A	B	C	D	E	F	G	H	Total
Deep Channel	2220.2	2514.5	1828.2	730.6	690.4	1460.0	808.1	624.2	10876.2
Permanently Flooded	7359.6	17323.0	3479.8	753.7	1162.7	2624.9	3554.6	1899.6	38157.9
Intermittently Exposed	2852.5	4014.5	854.7	250.8	354.8	671.0	861.8	597.9	10457.9
Side Channel	38.4	3.8	24.7	2.6	3.9	87.9	5.5	0.0	166.8
Channel Bar	2.6	2.8	7.3	7.5	15.4	8.8	15.5	0.5	60.3
Tributary Delta		9.8	1.7	26.2	0.2		287.6	46.7	372.1
Channel Bedrock				0.6	0.3	9.0			9.9
Artificial Waterbody					2.3	1.5		1.8	5.5
Unknown Depth	2126.7	290.1	213.1	419.8	268.5	739.3	107.5	167.6	4332.6
Lower Flooded Surge Plain	418.7	1800.5	247.5						2466.7
Upper Flooded Surge Plain	343.0	2179.2	975.8						3497.9
Undifferentiated Flooded Surge Plain	39.3	855.3	234.9						1129.5
Tidal Channel	49.8	329.0	240.0						618.8
Permanently Flooded Tertiary Channel		106.9	29.4						136.4
Intermittently Exposed Tertiary Channel		283.2	57.5						340.7
Floodplain	137.9	480.0	580.7	1039.1	653.1	2178.2	3255.8	553.5	8878.3
Natural Levee	63.7	464.3	1205.1	248.8	1170.0	5992.3	1231.0	179.7	10554.9
Lake Bed						2817.1	249.4		3066.5
Floodplain Channel	224.4	246.5	279.6	58.9	45.0	302.0	189.1	2.0	1347.4
Tie Channel					0.8	135.1	9.4		145.3
Tributary Fan	66.0	246.6	268.4	96.2	81.8	285.5	101.5	827.1	1973.2
Tributary Valley (Outside Floodplain)	311.3	931.1	41.5	306.4	1528.9	611.0	414.6	40.9	4185.8
Minor Tributary	27.8		4.4	9.2	15.1	30.4	4.7	45.3	136.8
Wetland	5871.4	3864.8	7418.7	1131.2	1564.4	3121.3	746.3	91.8	23809.9
Lake/Pond	135.7	28.4	40.2	199.5	293.5	3411.9	538.2	144.3	4791.8
Unknown	10.0	2.2	0.2	0.4	21.9	0.7	0.3	15.8	51.6
Bedrock	42.0	41.6	128.0	215.4	0.8	233.7	72.9	6.9	741.2
Dune	2203.9	0.1				1213.5	12.7	77.5	3507.8
Volcanogenic Delta				1289.2	2230.7		377.1		3897.0
Volcanogenic Delta (CR Floods)				262.4	202.0		645.1		1109.6
Terrace	57.3	22.2	25.9	3.6	53.3	1073.6	817.8		2053.7
Landslide Deposit	0.5	43.8	121.9	0.3	20.2	5.3		405.4	597.5
Artificial Beach/Bar					0.3	0.5	0.8		1.5
Dredge Disposal Area	87.5	550.3	584.0	895.2	411.4	337.4	223.9		3089.9
Filled Area	214.3	141.8	22.4	35.8	13.0	5.2	47.4	23.5	503.2
Developed Floodplain	336.4	30.1	299.8	1600.5	178.6	2934.7	2110.6	379.3	7869.9

Considerable habitat has been lost in Reaches D, F and G, as evidenced by the high amount of developed floodplain in those reaches.

Level 6: Biocatenae broken down by reach

Note: Areas in hectares (ha)

		Reach								Estuary
	Biocatena	A	B	C	D	E	F	G	H	Total
Tidal	Tidal Mud	58.2	380.1	0.1			3.7		0.2	442.2
	Tidal Herbaceous Wetland	562.8	2,057.5	619.6	26.2	91.2	1,066.4	144.7	33.9	4,602.3
	Tidal Deciduous Wetland	0.5	162.9	592.0	106.4	124.8	1,253.7	106.7	1.9	2,348.8
	Tidal Mixed Scrub-shrub Wetland		1.0				1.8			2.8
	Tidal Scrub-shrub Wetland	7.7	1,102.6	258.2	12.4	17.2	10.3	32.4	38.9	1,479.7
	Tidal Coniferous Wetland	2.9	267.9	0.0						270.8
	Tidal Mixed Forest Wetland	2.9	111.5							114.4
Non-tidal	Non-tidal Deciduous Wetland	216.7	88.8	343.6	136.7	295.0	623.6	107.3	216.8	2,028.5
	Non-tidal Scrub-shrub Mixed Wetland	25.8	12.7	6.8	4.9	18.7	4.9	0.5	32.3	106.6
	Non-tidal Herbaceous Wetland	101.0	172.7	58.0	145.9	175.9	656.2	250.5	85.4	1,645.6
	Non-tidal Scrub-shrub Developed Wetland	1.3	1.3		0.2				0.4	3.2
	Non-tidal Scrub-shrub Wetland	63.7	143.4	134.3	11.0	6.7	112.2	14.9	61.6	547.9
	Non-tidal Mixed Wooded Wetland	500.6	1.5							502.1
	Non-tidal Mixed Coniferous Wetland	177.1	76.8	125.0					3.1	382.0
	Non-tidal Coniferous Wetland	65.9	859.3	5.2				0.0	0.7	931.2
Diked	Diked Herbaceous Mixed Wetland	2.7	12.9	7.7	23.5	13.0	0.9	7.7	1.2	69.5
	Diked Herbaceous Wetland	319.6	943.3	102.4	124.6	223.2	621.2	361.6	43.0	2,739.1
	Diked Scrub-shrub Mixed Wetland	108.7	0.1	1.7		2.9	1.2		1.2	115.6
	Diked Scrub-shrub Wetland	652.4	107.3	21.3	1.9	0.4	8.6	22.0		814.1
	Diked Deciduous Wetland	517.2	182.0	86.5	26.5	54.0	170.5	112.9	3.2	1,152.9
	Diked Coniferous Wetland	38.2	20.5	0.0		0.1				58.8
Agriculture/Developed	Agricultural Tree Farms		88.1	145.1		44.2	89.2			366.7
	Agricultural Mixed Wetland	231.5	29.8	3.7		179.7	483.2			928.0
	Agricultural	2,437.6	4,055.3	7,600.8	484.1	5,210.6	11,578.3	1,159.7	57.4	32,583.8
	Developed Mixed	151.1	35.5	210.4	65.4	29.0				491.3
	Developed Coniferous Wetland Forest	3.6								3.6
	Developed Urban Impervious	682.2	140.6	1,017.5	4,327.1	249.4	2,774.9	5,825.9	414.0	15,431.8
	Developed Open Space Mixed			114.2	5.6					119.8
	Developed Open Space	18.7	40.5	43.0	77.4	22.9	4.5	440.9	24.7	672.6
Upland	Mixed Deciduous Forest		224.5	10.7	25.8	56.6	3.3	4.9		325.9
	Upland Coniferous Forest	359.4	390.3	37.7	95.7	1,085.8	60.8	410.5	574.5	3,014.7
	Upland Herbaceous	4.5	59.5	142.9	780.0	25.2	590.2	698.0	157.2	2,457.5
	Upland Deciduous Forest	51.2	125.2	405.6	527.6	225.5	415.8	671.4	440.6	2,862.9
	Upland Scrub-shrub	4.8	0.0				0.1			4.9
	Upland Wooded	0.4	5.5	11.2	11.6	3.2	12.2	38.7	3.2	85.9
	Bare	12.0	12.8	5.1	161.0	115.8	38.7		3.4	348.8
Other	Rock		0.2						0.1	0.3
	Aquatic Vegetation		4.5	7.3	1.7	17.8	157.1	4.6	31.6	224.5
	Water	208.6	563.5	585.9	237.4	123.4	3,214.4	925.9	110.1	5,969.3
	Sand	17.8	171.3	136.4	7.5	3.4	9.6	15.5	17.6	379.1

Reach F has more land in agriculture than any other reach.

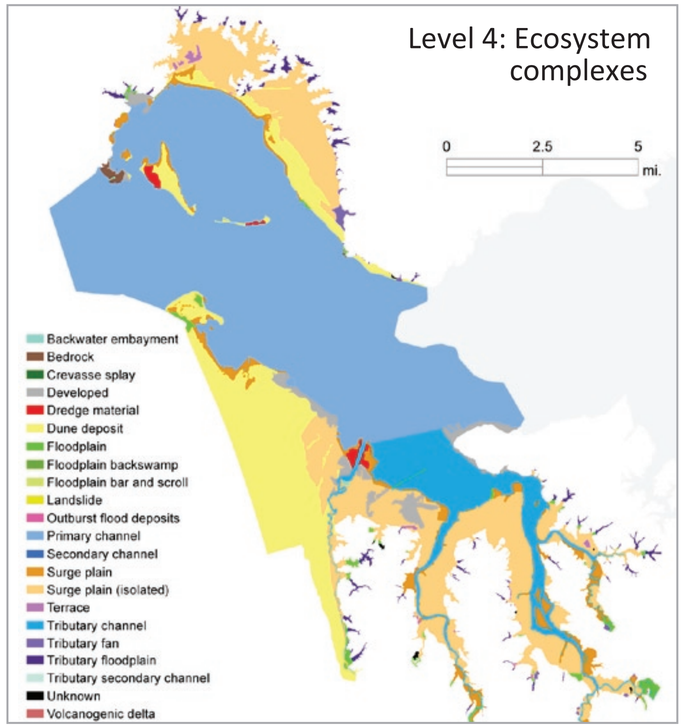
In Reaches D and G, the acreage of "developed urban impervious" biocatena is at least five times that of any other biocatena in those reaches.

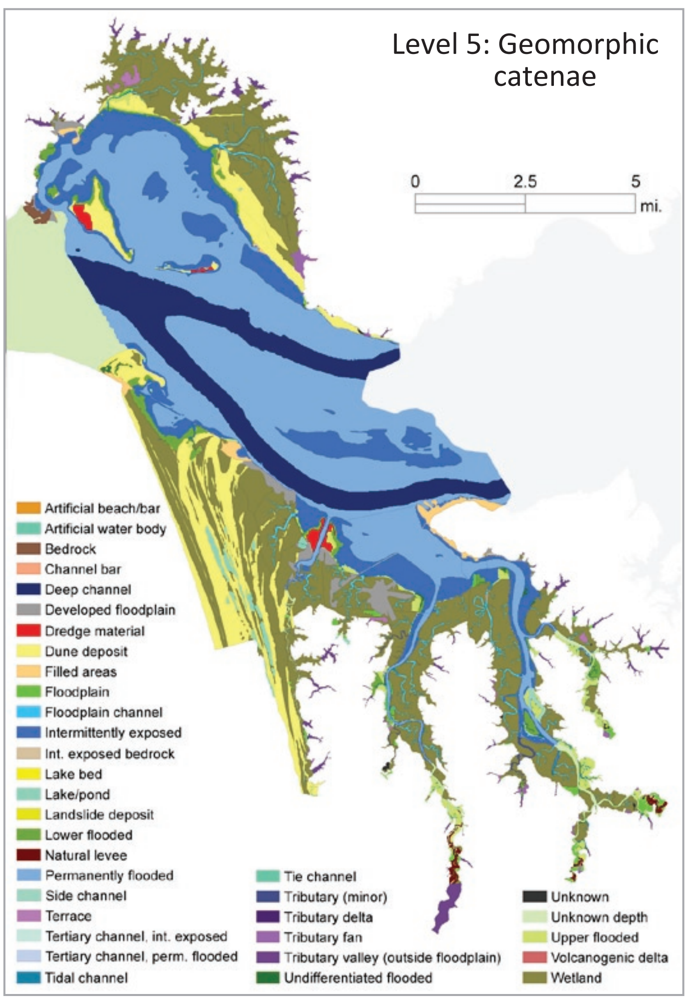
Reach A

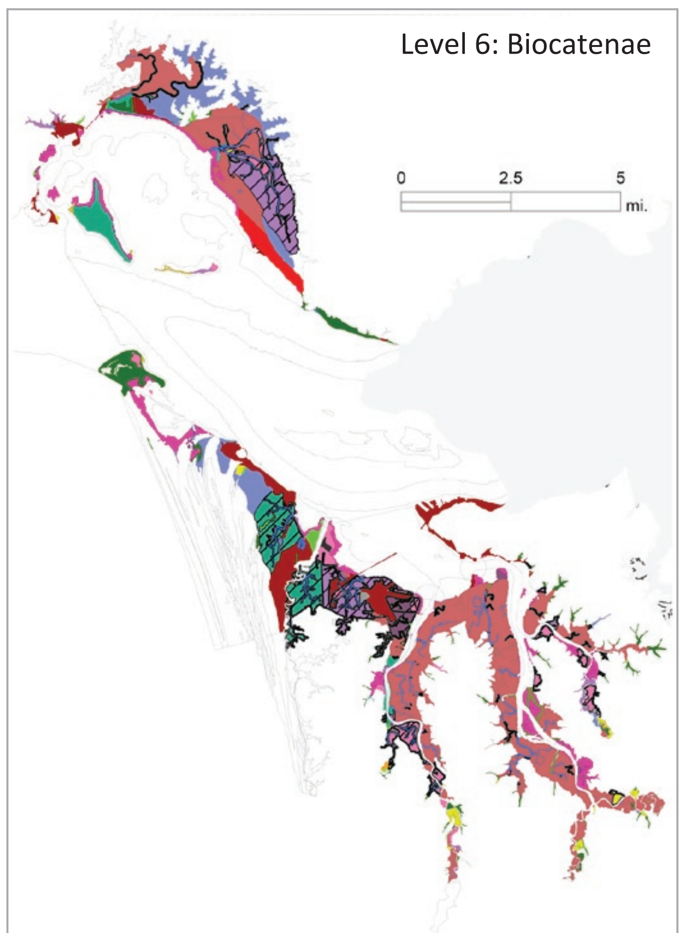
To view maps in greater detail, go to www.estuarypartnership.org/columbia-river-estuary-ecosystem-classification

Reach A: Summary Statistics

	AREA (ha)
Total Area	25240.71
Channel and Backwater	14598.29
Surge Plain	5748.12
Floodplain	635.10
Non-fluvial, Relict or Prehistoric	3654.76
Dominantly Anthropogenic	604.45
Tributary Confluence (count)	3
Anthropogenic Area	7451.46
Altered	3332.53
Artificial	675.75
Drained	2885.51
Unknown	557.67







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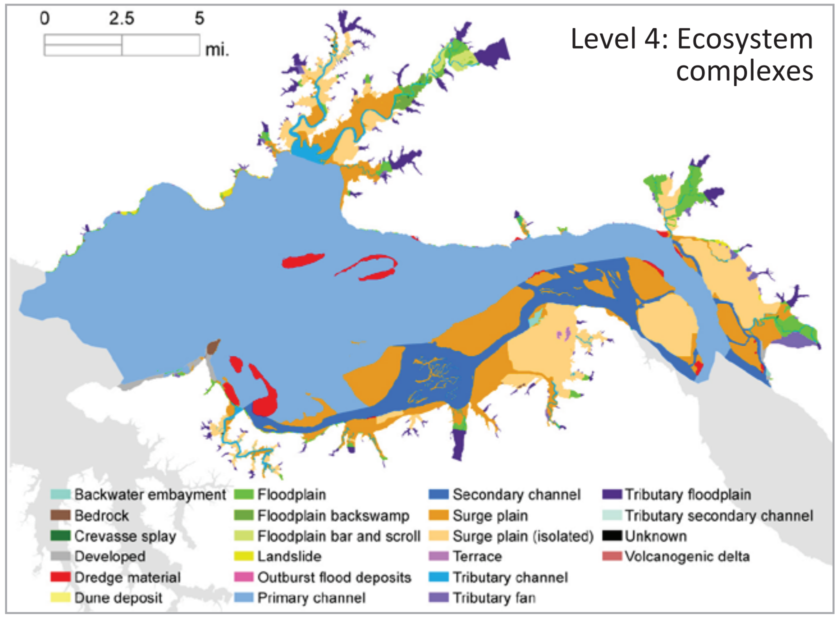
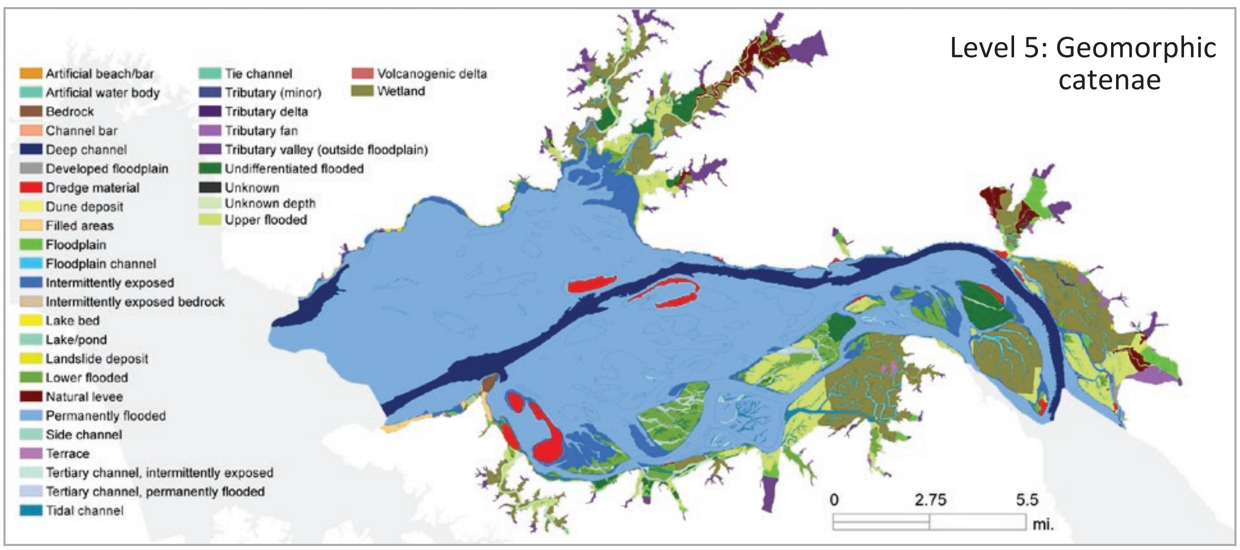
Reach B

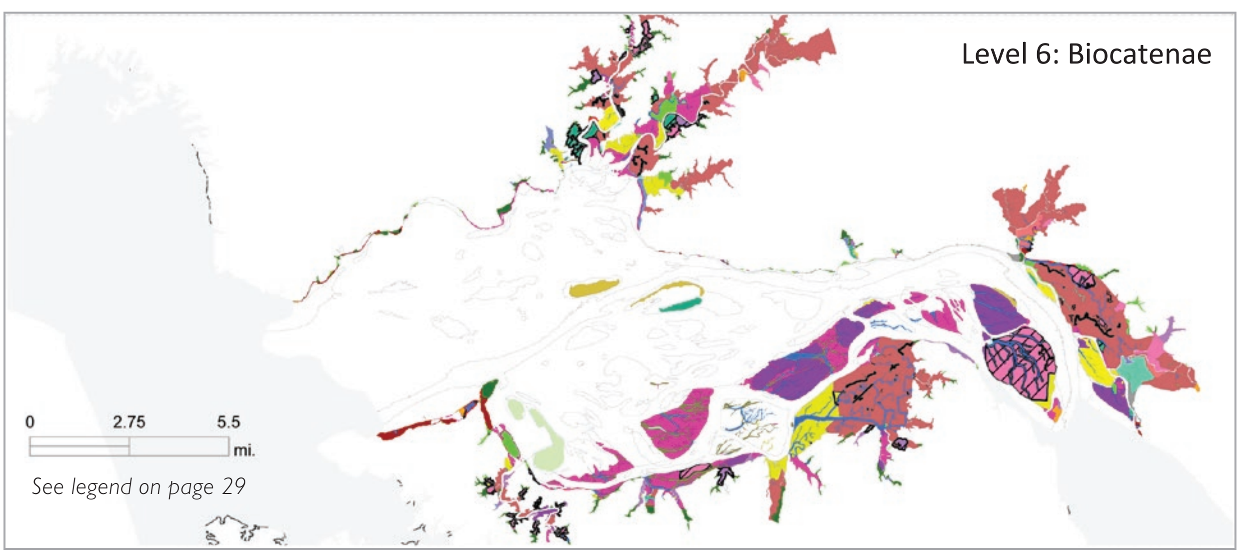
Reach B: Summary Statistics

	AREA (ha)
Total Area	36806.29
Channel and Backwater	24158.41
Surge Plain	9551.74
Floodplain	2287.16
Non-fluvial, Relict or Prehistoric	107.95
Dominantly Anthropogenic	701.03
Tributary Confluence (count)	11
Anthropogenic Area	6293.75
Altered	1930.97
Artificial	760.75
Drained	2844.03
Unknown	758.00

To view maps in greater detail, go to www.estuarypartnership.org/columbia-river-estuary-ecosystem-classification







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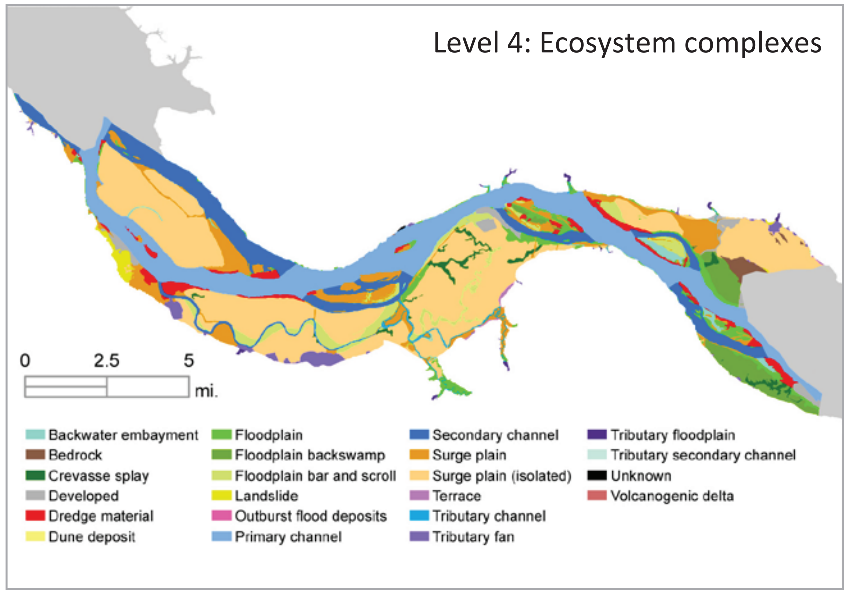
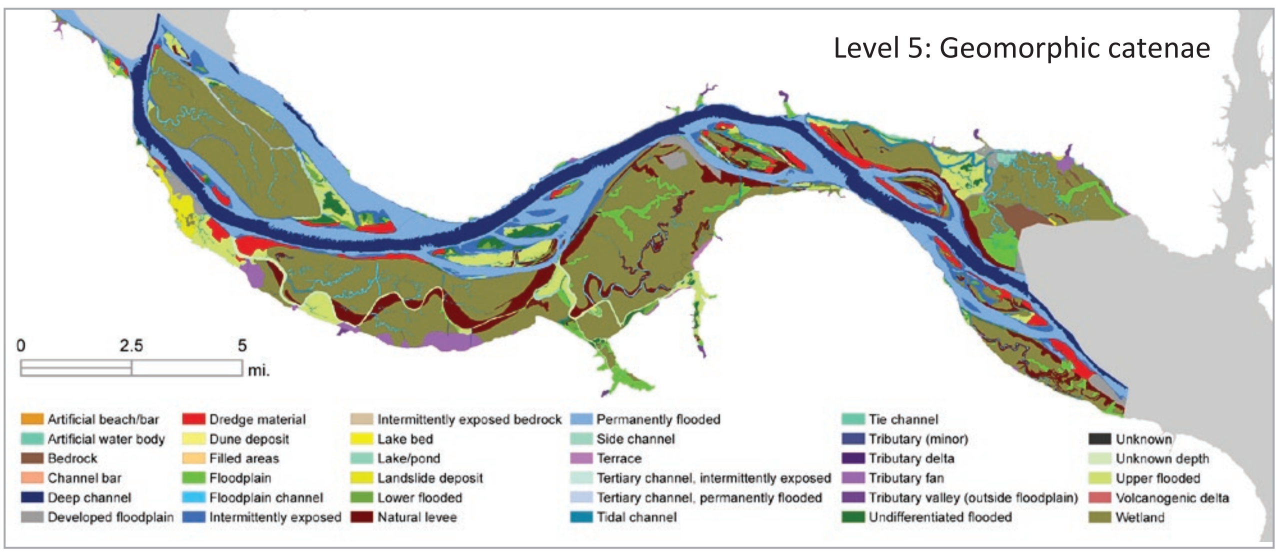
Reach C

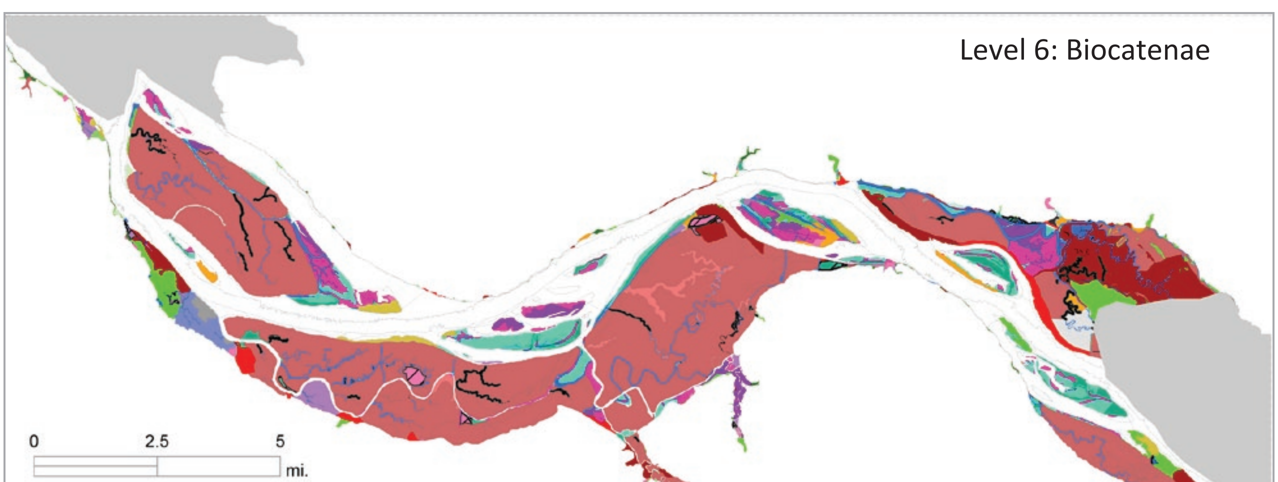
To view maps in greater detail, go to:
www.estuarypartnership.org/columbia-river-estuary-ecosystem-classification

Reach C: Summary Statistics

	AREA (ha)
Total Area	19215.67
Channel and Backwater	6408.07
Surge Plain	8745.44
Floodplain	2875.51
Non-fluvial, Relict or Prehistoric	283.16
Dominantly Anthropogenic	903.49
Tributary Confluence (count)	4
Anthropogenic Area	10299.36
Altered	1882.59
Artificial	1042.88
Drained	6259.19
Unknown	1114.70







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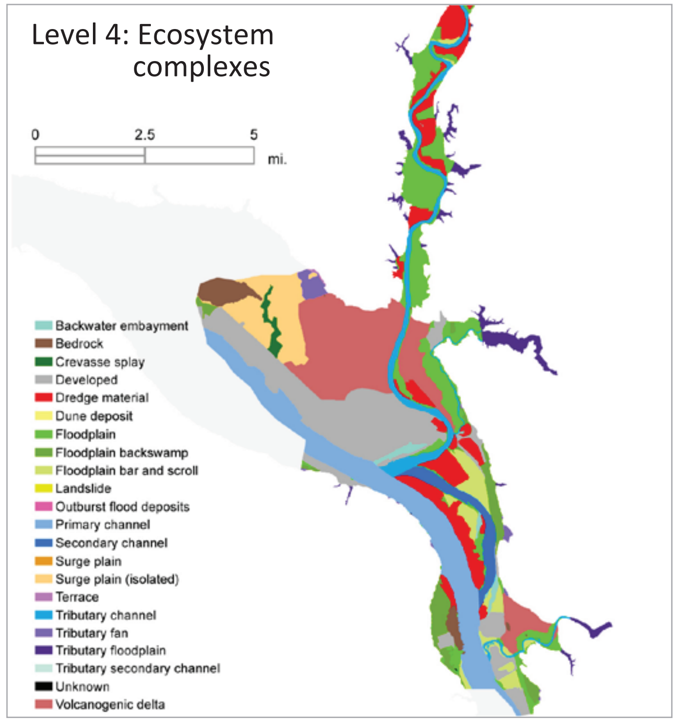
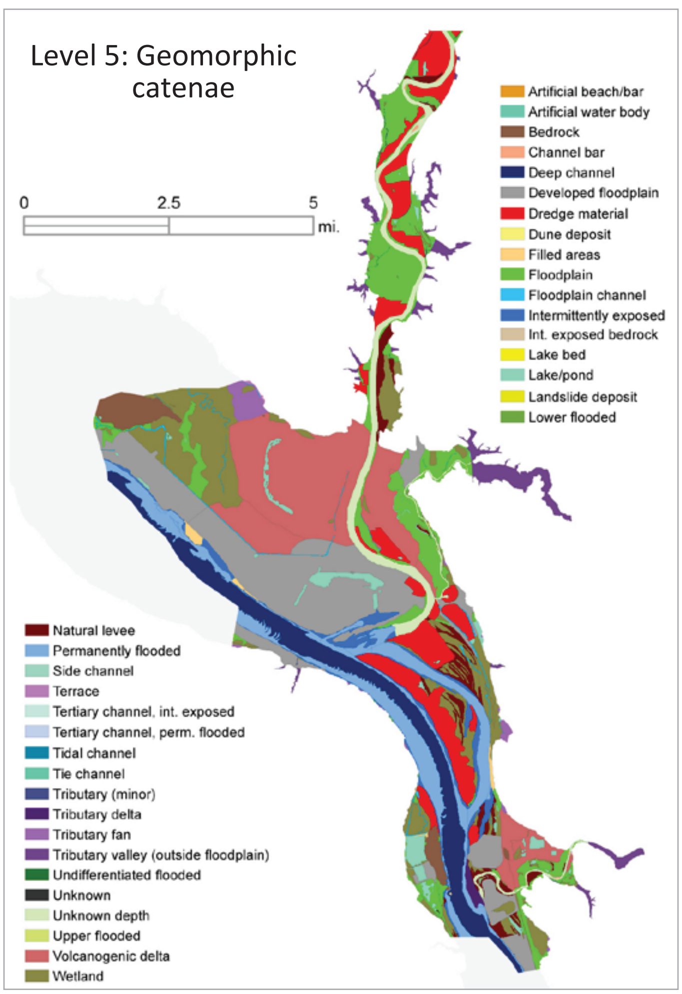
Reach D

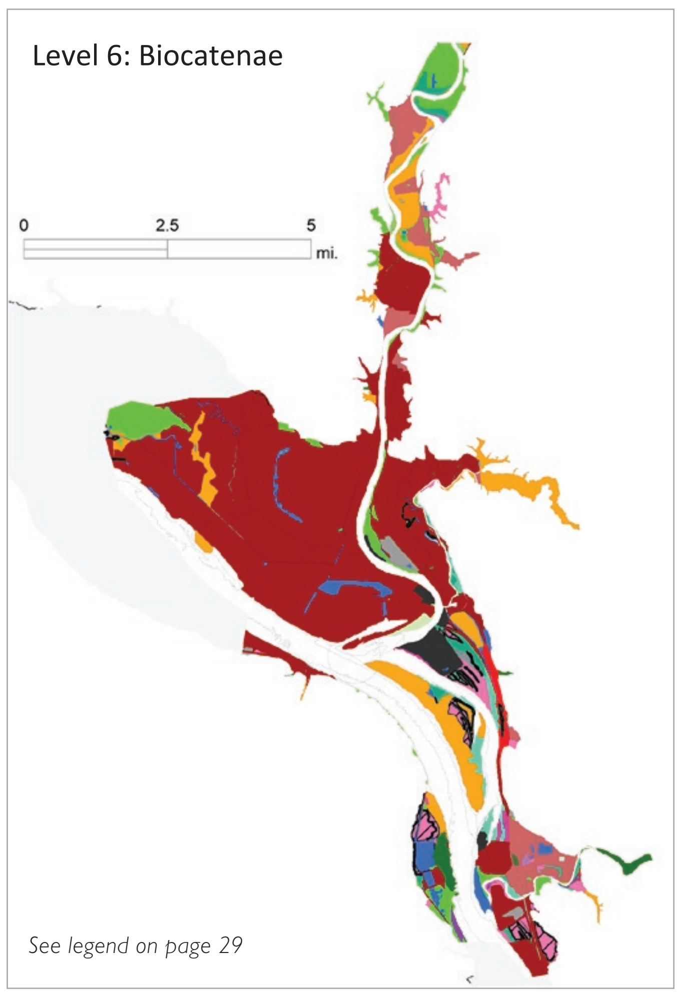
To view maps in greater detail, go to www.estuarypartnership.org/columbia-river-estuary-ecosystem-classification



Reach D: Summary Statistics

	AREA (ha)
Total Area	9583.69
Channel and Backwater	2191.69
Surge Plain	579.13
Floodplain	2357.11
Non-fluvial, Relict or Prehistoric	1835.00
Dominantly Anthropogenic	2620.76
Tributary Confluence (count)	2
Anthropogenic Area	6885.79
Altered	602.96
Artificial	2797.25
Drained	644.59
Unknown	2840.98



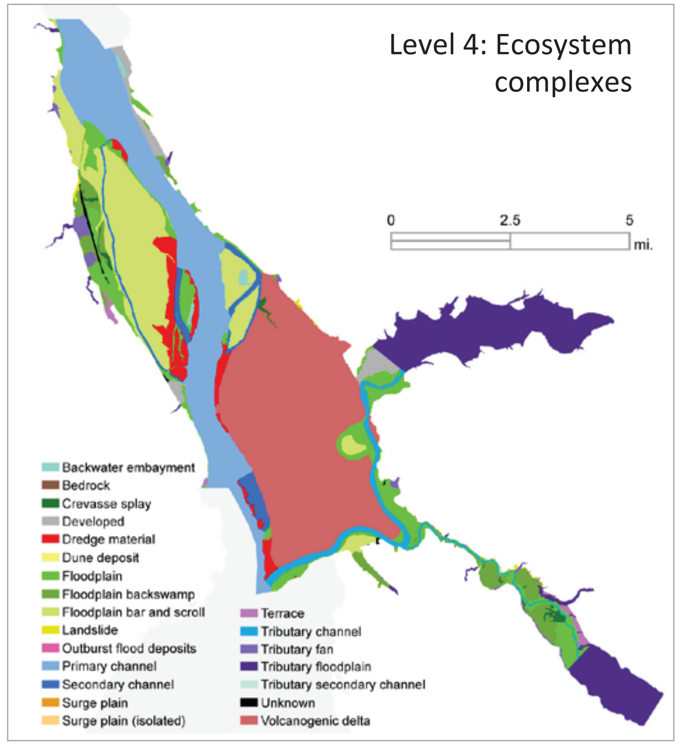


Reach E

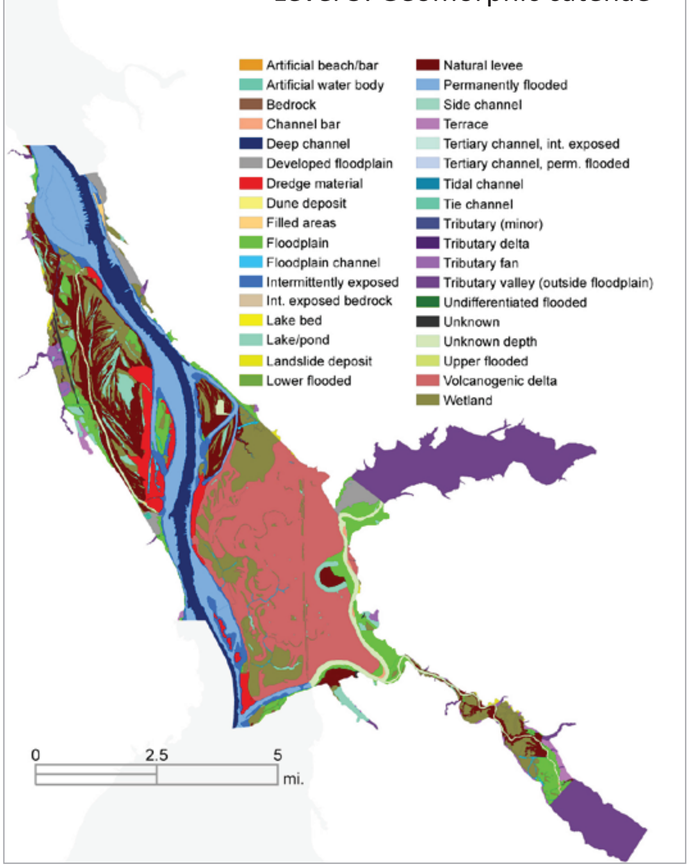
To view maps in greater detail, go to:
www.estuarypartnership.org/columbia-river-estuary-ecosystem-classification

Reach E: Summary Statistics

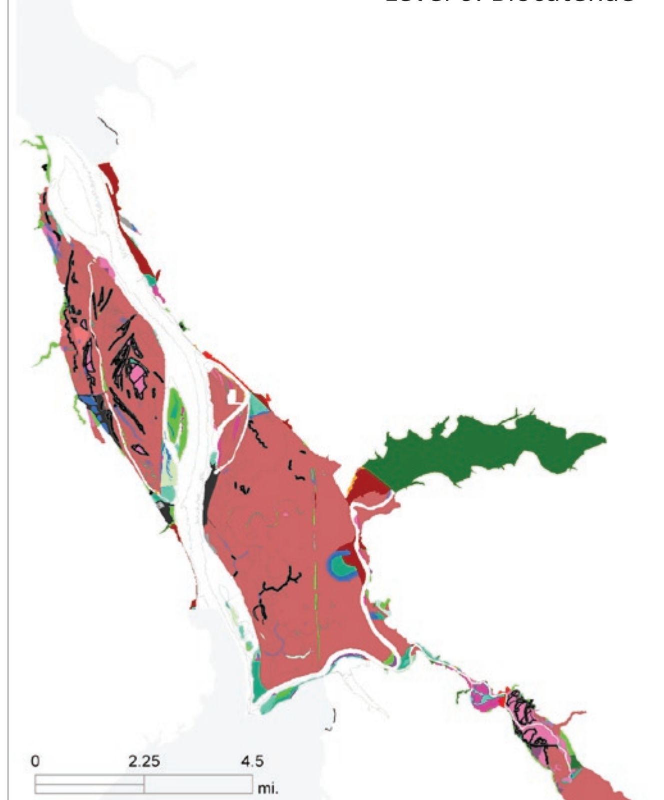
	AREA (ha)
Total Area	10983.15
Channel and Backwater	2494.77
Surge Plain	0
Floodplain	4626.53
Non-fluvial, Relict or Prehistoric	3258.71
Dominantly Anthropogenic	603.13
Tributary Confluence (count)	1
Anthropogenic Area	6743.5
Altered	827.25
Artificial	595.87
Drained	374.60
Unknown	4945.77



Level 4: Ecosystem complexes



Level 5: Geomorphic catenae



Level 6: Biocatenae

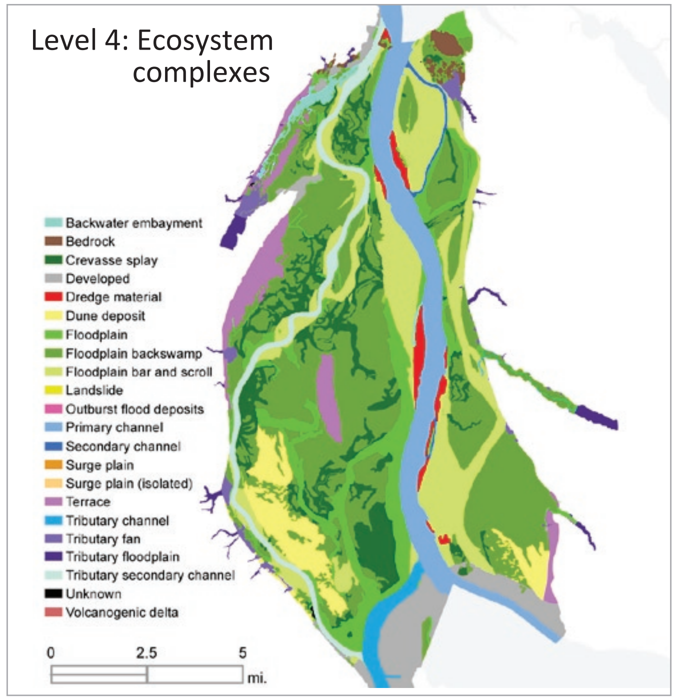
See legend on page 29

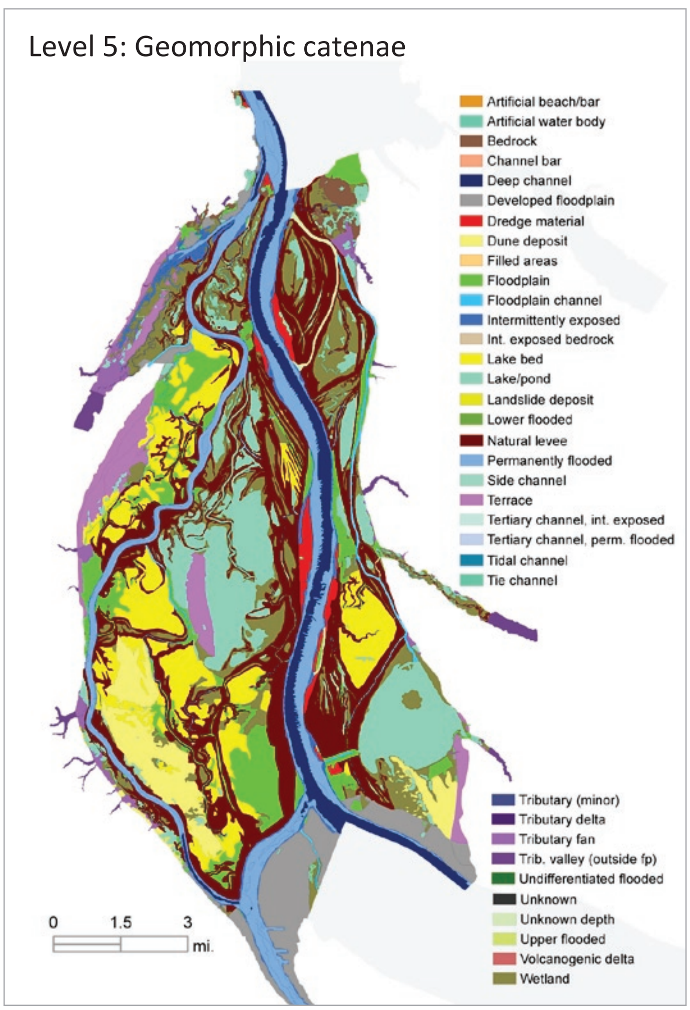
Reach F

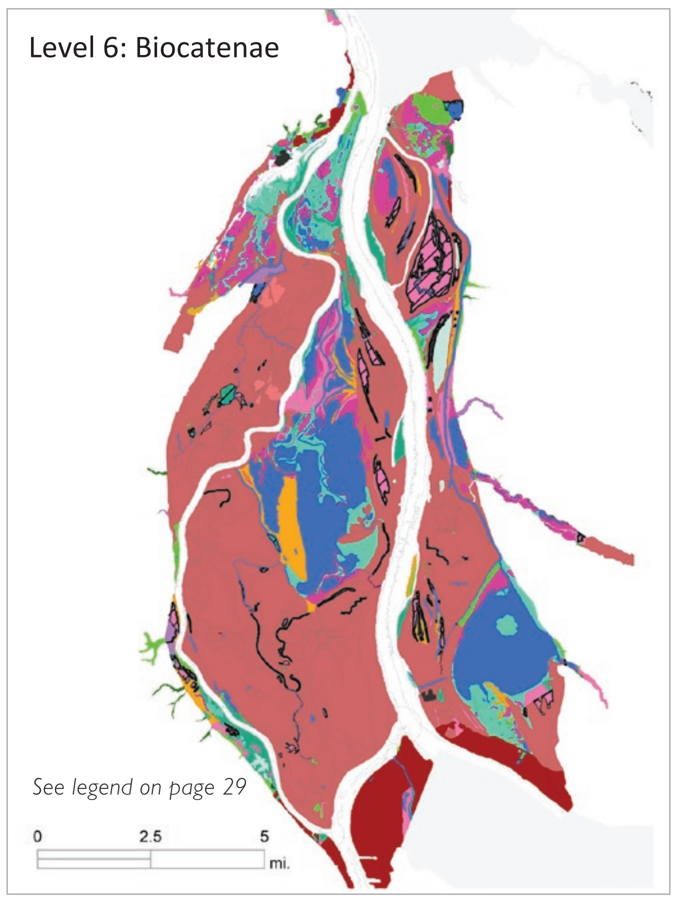
To view maps in greater detail, go to www.estuarypartnership.org/columbia-river-estuary-ecosystem-classification

Reach F: Summary Statistics

	AREA (ha)
Total Area	30291.78
Channel and Backwater	5602.43
Surge Plain	0
Floodplain	18836.16
Non-fluvial, Relict or Prehistoric	2533.93
Dominantly Anthropogenic	3319.26
Tributary Confluence (count)	3
Anthropogenic Area	17845.52
Altered	3360.15
Artificial	3491.20
Drained	3310.42
Unknown	7683.75







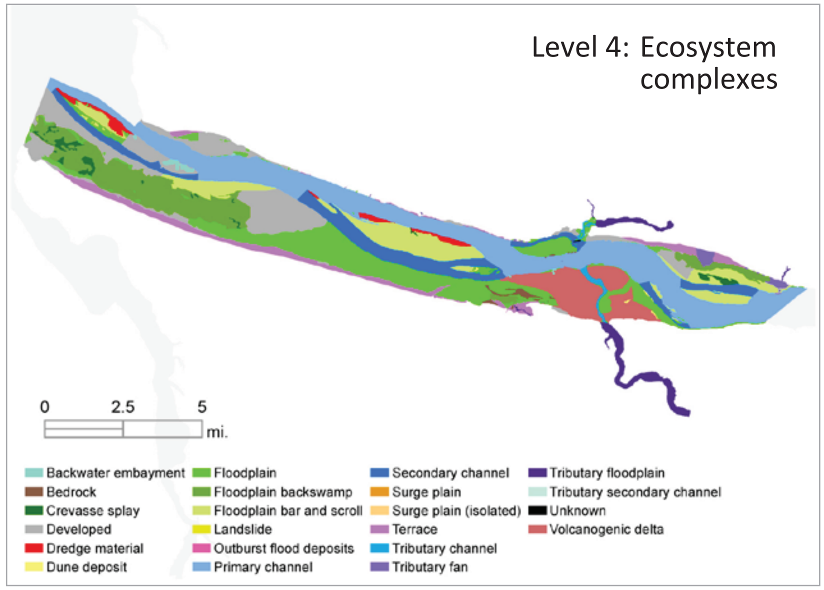
NOTE: Because of space constraints, the maps on this page do not display the southernmost portion of Reach F. For full maps of Reach F, see the classification data at http://www.estuarypartnership.org/columbia-river-estuary-ecosystem-classification.

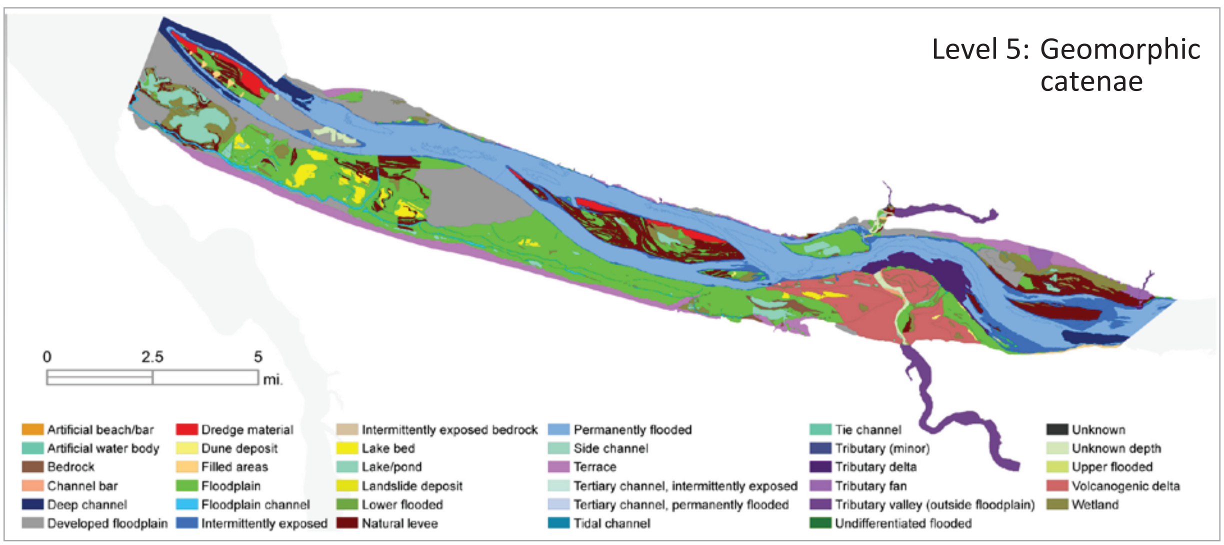
Reach G

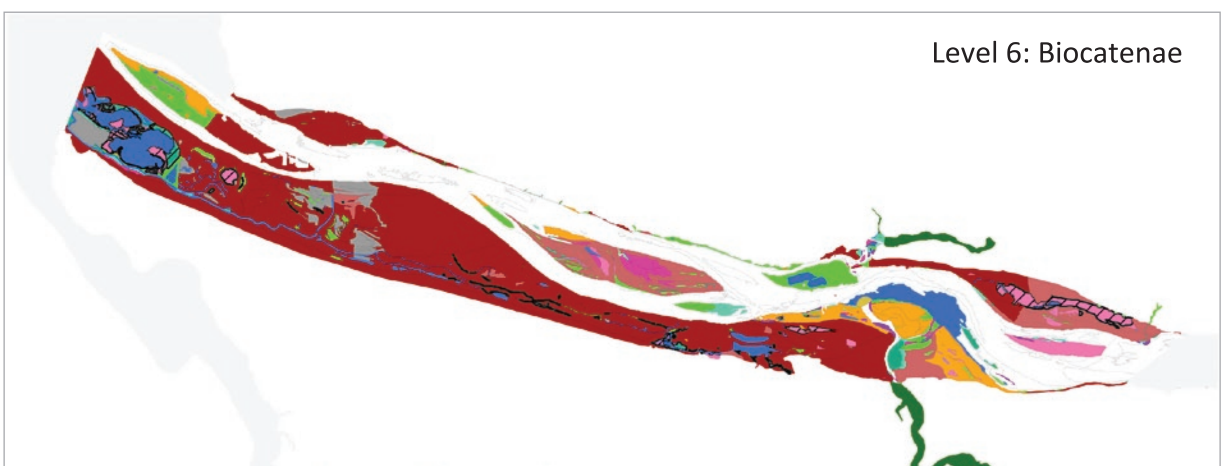
To view maps in greater detail, go to:
www.estuarypartnership.org/columbia-river-estuary-ecosystem-classification

Reach G: Summary Statistics

	AREA (ha)
Total Area	16689.34
Channel and Backwater	5640.63
Surge Plain	0
Floodplain	6701.64
Non-fluvial, Relict or Prehistoric	2003.42
Dominantly Anthropogenic	2343.65
Tributary Confluence (count)	2
Anthropogenic Area	8024.63
Altered	3568.26
Artificial	2535.97
Drained	383.36
Unknown	1537.05







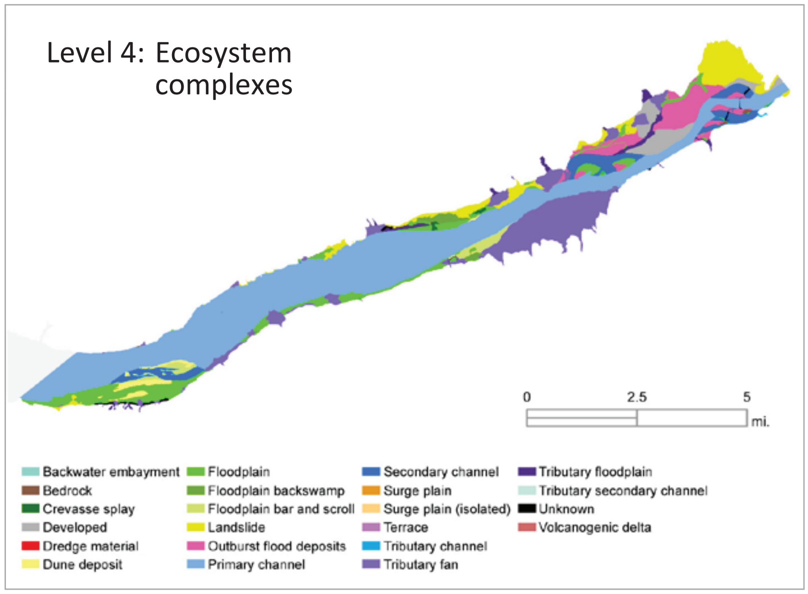
See legend on page 29

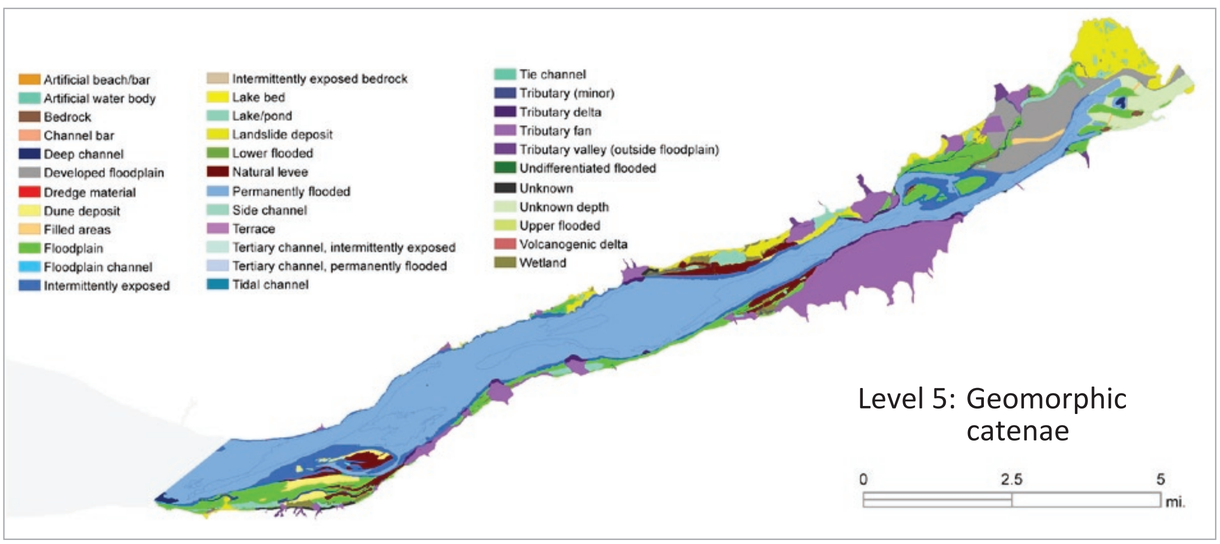
Reach H

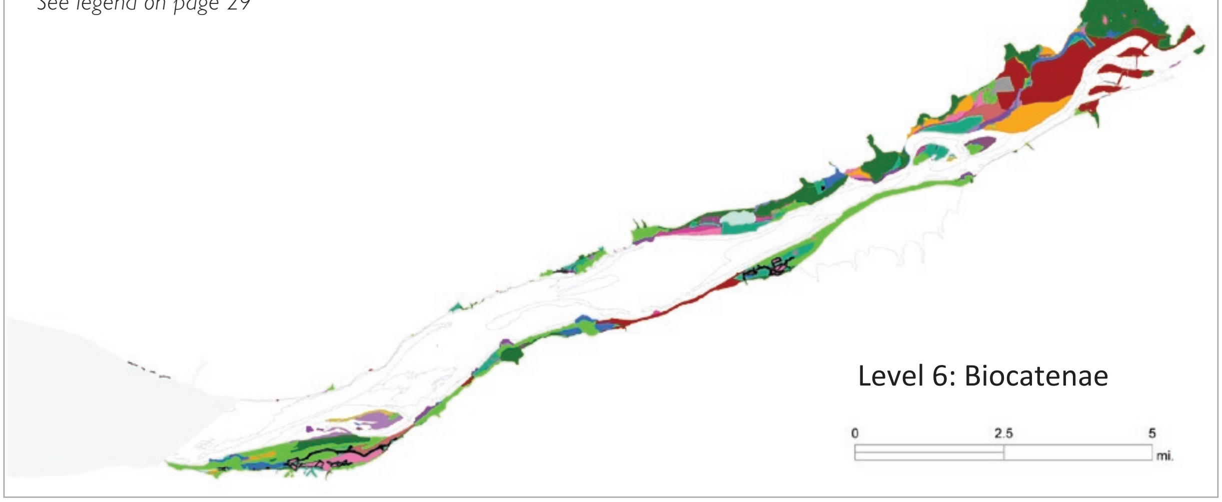
To view maps in greater detail, go to www.estuarypartnership.org/columbia-river-estuary-ecosystem-classification

Reach H: Summary Statistics

	AREA (ha)
Total Area	6131.25
Channel and Backwater	3337.51
Surge Plain	0
Floodplain	1660.54
Non-fluvial, Relict or Prehistoric	924.52
Dominantly Anthropogenic	208.68
Tributary Confluence (count)	0
Anthropogenic Area	3976.08
Altered	450.5
Artificial	494.04
Drained	
Unknown	3031.54







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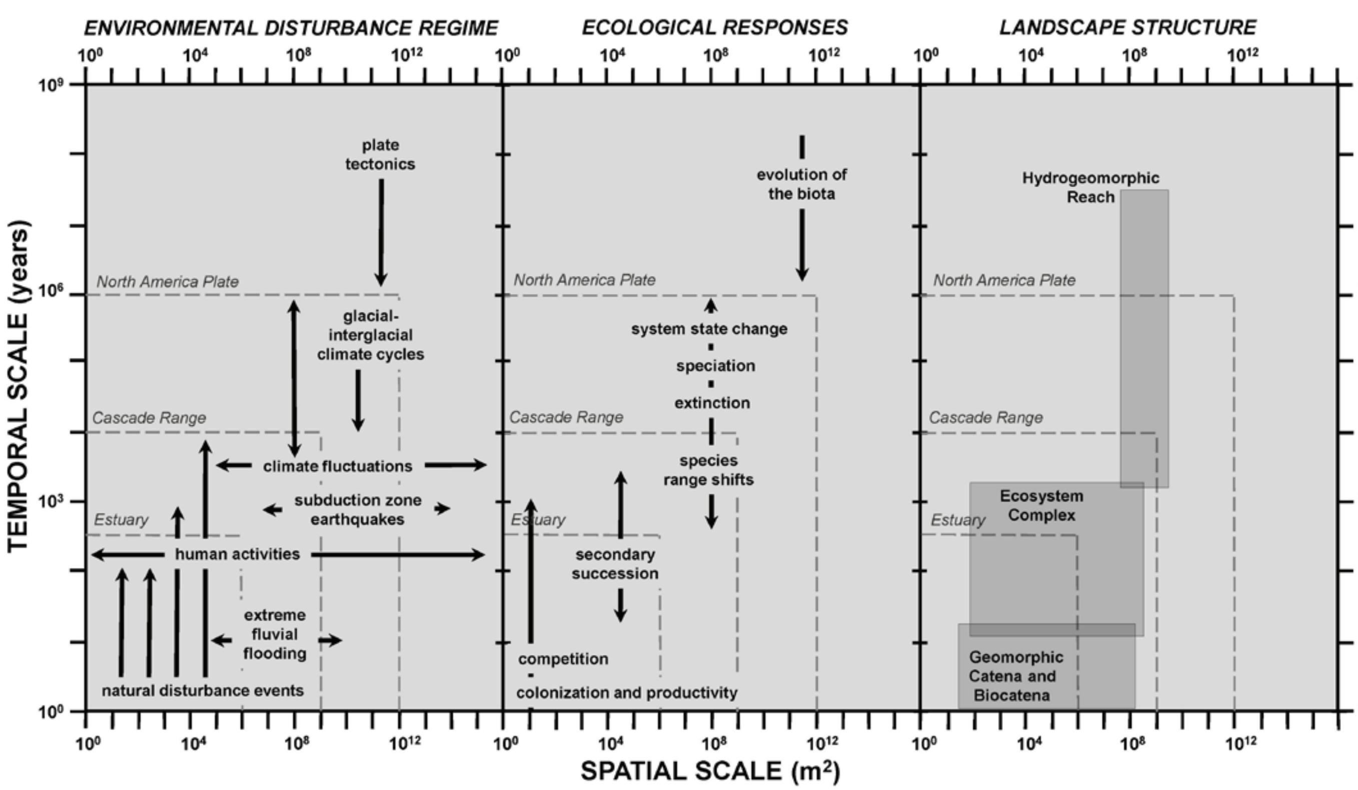
Level 6: Biocatenae

- Not Classified
- Agricultural/Agricultural Mixed Wetland
- AgriculturalTree Farms
- Developed Mixed Use
- Developed Coniferous Wetland Forest
- Developed Urban Impervious
- Developed Open Space Mixed
- Developed Open Space
- Diked Herbaceous Mixed Wetland
- Diked Herbaceous Wetland
- Diked Scrub-Shrub Mixed Wetland
- Diked Scrub-Shrub Wetland
- Diked Deciduous Wetland
- Diked Coniferous Wetland
- Non-tidal Deciduous Wetland
- Non-tidal Scrub-Shrub Mixed Wetland
- Non-tidal Herbaceous Wetland
- Non-tidal Scrub-shrub Developed Wetland
- Non-tidal Scrub-shrub Wetland
- Non-tidal Mixed Forest/Scrub-Shrub Wetland
- Non-tidal Coniferous Wetland
- Rock
- Aquatic Vegetation
- Water
- Sand
- Tidal Mud Flat
- Tidal Herbaceous Wetland
- Tidal Deciduous Wetland
- Tidal Mixed Scrub-Shrub Wetland
- Tidal Scrub-Shrub Wetland
- Tidal Coniferous Wetland
- Tidal Mixed Forest Wetland
- Mixed Deciduous Forest
- Upland Herbaceous
- Upland Coniferous Forest
- Upland Deciduous Forest
- Upland Scrub-Shrub
- Upland Wooded
- Bare

DELCOURT DIAGRAM: Levels 3 through 6 of the classification fit within a larger, hierarchical structure of environmental disturbances, ecological responses, and landscape structures that exist at various spatial and temporal scales. Adopted from Delcourt et al. (1988).[20]



[20] *Delcourt, H.R., and Delcourt, P.A. 1988. Quaternary landscape ecology: relevant scales in space and time. Landscape Ecology, 2, 23-44.*

Advancing science, protecting ecosystems, building connections to sustain the Columbia for all time.

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