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Puget Sound Habitat Status and Trends 2023 Update: Delta Habitats and Overwater Structures

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Northwest Fisheries Science Center

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Puget Sound Habitat Status and Trends 2023 Update: Delta Habitats and Overwater Structures

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Acknowledgements

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Executive Summary

Using the protocols of NOAA's Salmon Habitat Status and Trends Monitoring Program, we updated the delta habitat data and overwater structure data for Puget Sound. The previously mapped delta habitats were based on imagery from 2010 to 2012, and the overwater structures were based on imagery from 2013 to 2016. Imagery years for this update are 2017 to 2021 for delta habitats and 2021 to 2022 for overwater structures.

We found that areas of tidal complexes and tidal flats increased in the Skagit and Snohomish River basins, but areas decreased in the Nisqually, Quilcene, and Skokomish River basins. Increases and decreases in other basins were relatively small. In contrast, lengths of tidal channels increased significantly in more than half of the deltas (Nooksack, Skagit, Stillaguamish, Snohomish, Nisqually, Union, Skokomish, Quilcene, and Elwha). Increases were due to both restoration actions and natural delta progradation, although increased imagery resolution also allowed to see and digitize more small tidal channels in the recent imagery than in past imagery. We did not quantify the separate sources of change, but our perception was that most large changes were natural or man-made rather than due to imagery resolution

It is clear that the selected delta habitat metrics provide different views of their status, so we suggest four guidelines for interpretation of the results.

1. Habitat area is the most appropriate metric for tidal channel complexes, which are not linear features. Functional edge habitats within tidal complexes are in the network of channels within the complex, so a linear measure of the edge length of a tidal channel complex is not a meaningful habitat metric.
2. Tidal flats are also not linear features, although the edge of a tidal flat is useable habitat and both the habitat area and habitat edge length are useful metrics.
3. Distributary channels and tidal channels are linear features, and useable habitat is typically along the edges of each channel. The center of distributaries in particular is often not suitable salmonid habitat, so the most useful metrics for distributary and tidal channels are the length and edge length metrics, but not the area metric.
4. Node density is ostensibly a measure of the delta habitat complexity, although the total number of nodes is largely a function of delta size and the node density is a function of delta width relative to delta length. Node density does not appear to be a useful metric for comparisons among deltas, but it may be useful for comparisons among time periods within each delta.

The number of overwater structures increased slightly in the Hood Canal Marine Basin and decreased in the Whidbey Basin. In contrast, areas of overwater structures remained virtually the same in Hood Canal, but decreased in both Whidbey Basin and the Strait of Juan de Fuca Basin. We noted that seasonal variation is significant for some structure types. This is especially noticeable with detachable floating docks and floats. We still included them in this analysis however since they impact nearshore habitats as they tend to be moved rather than removed.

Introduction

The Northwest Fisheries Science Center developed monitoring protocols for large river and floodplain habitats, delta habitats, and overwater structures to track trends in habitat features over time in Puget Sound (Beechie et al. 2017, Stefankiv et al. 2019). The protocols were originally developed for the National Marine Fisheries Service (NMFS) to inform 5-year status reviews for salmon and steelhead listed under the Endangered Species Act (ESA). While these metrics have not been incorporated directly into the Puget Sound vital signs, they inform the condition of nearshore and estuarine habitat conditions tracked in the vital signs.

In this project we updated the delta habitat data and the overwater structure data. The previously mapped delta habitats were based on imagery from 2010 to 2012, and the overwater structures were based on imagery from 2013 to 2016. Imagery years for this update are 2017 to 2021 for delta habitats and 2021 to 2022 for overwater structures.

Methods Summary

Monitoring protocols for overwater structures and delta habitats are described in detail in Stefankiv et al. (2019), and summarized briefly here. All features are digitized from aerial and satellite imagery in ArcGIS Pro 3.1.2 (ESRI, 2023), and data files are uploaded to the NOAA Salmon Habitat Status and Trends website (https://www.fisheries.noaa.gov/resource/map/salmon-habitat-status-and-trend-monitoring-program-data).

Delta Habitats

We digitized four tidal channel feature types in each delta unit: distributary channels, tidal channels, tidal channel complexes, and tidal flats. Definitions of the four feature types are in Table 1. We used two source GIS layers for measuring habitat features in deltas: 1) the aerial imagery layer, and 2) the delta polygon layer. The aerial and satellite imagery is the data source for mapping habitat features, and the delta polygons set the boundaries for the habitat measurements in each delta. We also created two new layers for the feature types digitized, a polygon layer for polygon features (distributaries, large tidal channels, tidal channel complexes, and tidal flats) and a polyline layer for linear features (small tidal channels). Features were digitized from the 30 cm resolution false-color 2017 HxGN Imagery Program aerial imagery, 30 cm resolution true-color 2018 and 2020 WorldView-3 satellite imagery, 15 cm resolution false-color 2019 Snohomish County aerial imagery, and 15 cm resolution false-color 2021 HxGN Imagery Program aerial imagery set at a 1:750-1:1000 scale. Detailed protocols for digitizing each feature type are in Stefankiv et al. (2019).

Table 1. Definition of delta habitat feature types.

Habitat Feature	Definition
Distributary channel	Channel with bankfull width greater than 2-3 meters that has a clear upstream connection to the main channel or other distributary, and is part or all of a continuous flow path from the river to the delta mouth. The primary distributary is the channel that conveys the greatest amount of river flow downstream as determined by the size of channels at the bifurcations.
Tidal Channel	Large tidal channels have a bankfull width of at least 2-3 meters without river connection at the upstream end. Small tidal channels have bankfull width <2-3 meters without river connection at the upstream end.
Tidal Channel Complex	Dense tidal channel networks that occur at the terminal fringe of the delta, with numerous channels <2-3 m wide.
Tidal Flat	Large un-vegetated or low-density vegetation surfaces that occur interior of delta boundaries. Primarily associated with restoration projects where tidal connection has recently been restored and an established channel network with vegetated edges has not yet formed.

Overwater Structures

We define marine overwater structures (OWS) as human-built structures that extend over intertidal areas and shade or otherwise disturb natural nearshore processes and habitats. One of the primary impacts of overwater structures on nearshore habitats is the excess shade they create, which alters nearshore habitats. Overwater structures included in the Salmon Habitat Status and Trends Monitoring Program (SHSTMP) inventory are listed in Table 2. We digitized these features if they were present up to 200 meters inland of the shoreline (i.e., features in tidal channels or tidally influenced stream and river channels). Fill features were not included because they have different ecological impacts than overwater structures, and it is difficult to tell if fill features are natural or artificial solely using aerial imagery.

Our OWS layer was originally adapted from DNR's marine overwater structure layer created with imagery dating from 2002-2006 (WDNR unpublished data; data layer created in 2007). We made several updates to the DNR layer and created a new protocol to reduce variability and provide a comprehensive baseline layer. That layer was completed in 2017 using 50 cm resolution true-color WorldView-2 satellite imagery, dating from 2013-2016, at a 1:300 - 1:1000 scale. In 2023, we made updates to the 2017 layer using

15 cm resolution true-color 2021 HxGN Imagery Program aerial imagery and 30 cm resolution true-color 2022 WorldView-3 satellite imagery. For both iterations, we also used Google Earth satellite imagery and the Washington State Department of Ecology Coastal Atlas Program's 2016-17 oblique shoreline photos (https://apps.ecology.wa.gov/shorephotoviewer) to better identify features where needed.

For this second OWS survey, we added features to the existing polygon layer containing features from the prior monitoring work. A new data field labeled with the image years used for the updates (2021-2022) was added, and presence/absence noted. In continuation from our previous survey protocols, a change for a particular structure is documented by assigning the same OWS_ID and noting presence/absence for each polygon. Some edits were made to features created from the previous monitoring work and are reflected in the 2021-2022 OWS polygon layer. Specifically, floats were moved to reflect the current image year (instead of adding a new feature). As aerial imagery has improved in quality, other edits were made at the surveyor's discretion. This was done when the existing polygon shape was determined to be incorrect due to image quality (verified using time series in Google Earth) or previous surveyor error. This means that some polygons created in the previous SHSTMP survey will have edits in the 2021-2022 OWS layer and that the 2021-2022 layer should be used for all analysis in the future. Detailed protocols for digitizing OWS feature types from our first survey, as well as information about calculating dominant land cover class for our analysis, are in Stefankiv et al. (2019). Data dictionaries for the layers are posted on the SHSTMP website (https://www.fisheries.noaa.gov/resource/map/salmon-habitat-status-and-trend-monitoring-program-data) along with the data layers.

Table 2. Overwater structure types and complexity attributes as entered in the database.

Structure Type	Structure Complexity
Dock/Pier	smalldock (<560 m^2), largedock (>560 m^2), marina, building, pilings, staircase
Bridge	bridge, culvert, unknown
Boat Rail	boat rail, boat ramp
Buoy/Float	float, buoy
Aquaculture	net pen, shellfish, unknown
Log boom	log boom

Data Summaries

We summarized changes in delta habitat types between imagery dates using four metrics:

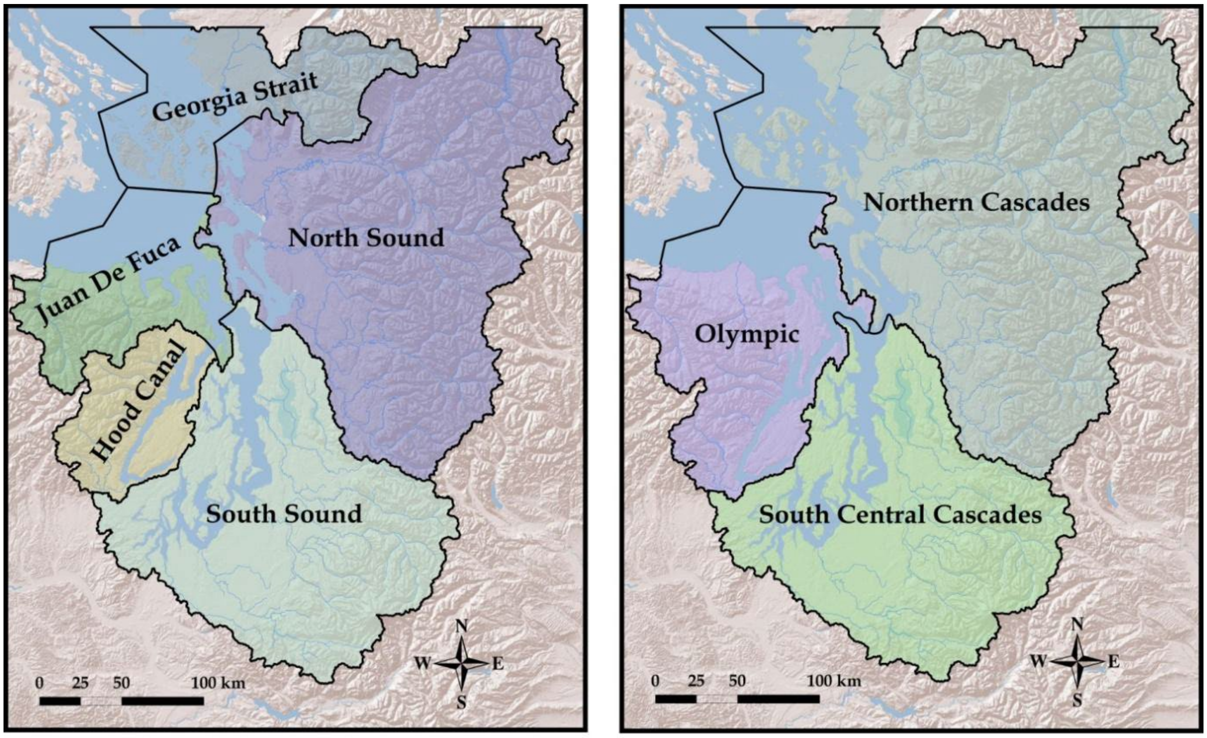
1. Habitat area
2. Habitat edge length
3. Habitat center-line length
4. Node density (number of bifurcations and confluences per km of main distributary length)

Habitat area is a common metric for most habitat typing systems, indicating the total area of habitat available. However, given that juvenile salmonids are more likely to use the edges of large channel features, we also report the length of channel edges for each habitat type. This second metric provides a measure of change in the portion of habitat units that is most likely used by juvenile salmonids. The center-line length is used primarily for calculating the node density (a measure of habitat complexity). Center lines are also used for calculating delta rearing capacity because channel length influences the connectivity of habitats and the relative densities of fish occupying habitats in different portions of a delta.

We summarized changes in overwater structures by reporting counts per kilometer of shoreline and overwater structure area per kilometer of shoreline. Count and area metrics give us a baseline for understanding how much of the nearshore is impacted and how these impacts change over time. Area and count summary results are reported for the two survey time periods, including all OWS features except shellfish and unknown structures in the aquaculture structure type category. Structures that were observed to have no decking were also excluded.

Results

We summarize changes in delta habitats by steelhead major population groups (MPG) in this report, but also include summaries by Chinook MPG in Appendix A. The boundaries of Major Population groups are shown in Figure 1. The Olympic MPG spans the Strait of Juan de Fuca and Hood Canal and includes the Skokomish, Hamma Hamma, Dosewallips, Duckabush, Big Quilcene, Dungeness, and Elwha deltas (delta locations in Figure 2), and is the least developed, with relatively small deltas and limited shoreline development relative to the other MPGs. The South Central Cascades MPG extends from Everett southward, containing the Duwamish, Puyallup, Nisqually, and Deschutes deltas. Two deltas in the South Central Cascades are relatively large and historically contained extensive salmonid rearing habitats, but urban development now limits current habitat areas (Puyallup and Duwamish). The Northern Cascades MPG extends from Everett northward, and includes the Snohomish, Stillaguamish, Skagit, Samish, and Nooksack deltas. Two of these deltas are among the largest in Puget Sound, but both have had extensive agricultural development that has limited habitat availability. Local stakeholders have recently focused estuary restoration actions in the Skagit, Snohomish, and Stillaguamish River deltas.



Chinook salmon major population groups

Steelhead major population groups

Figure 1. Boundaries of Chinook salmon and steelhead major population groups.

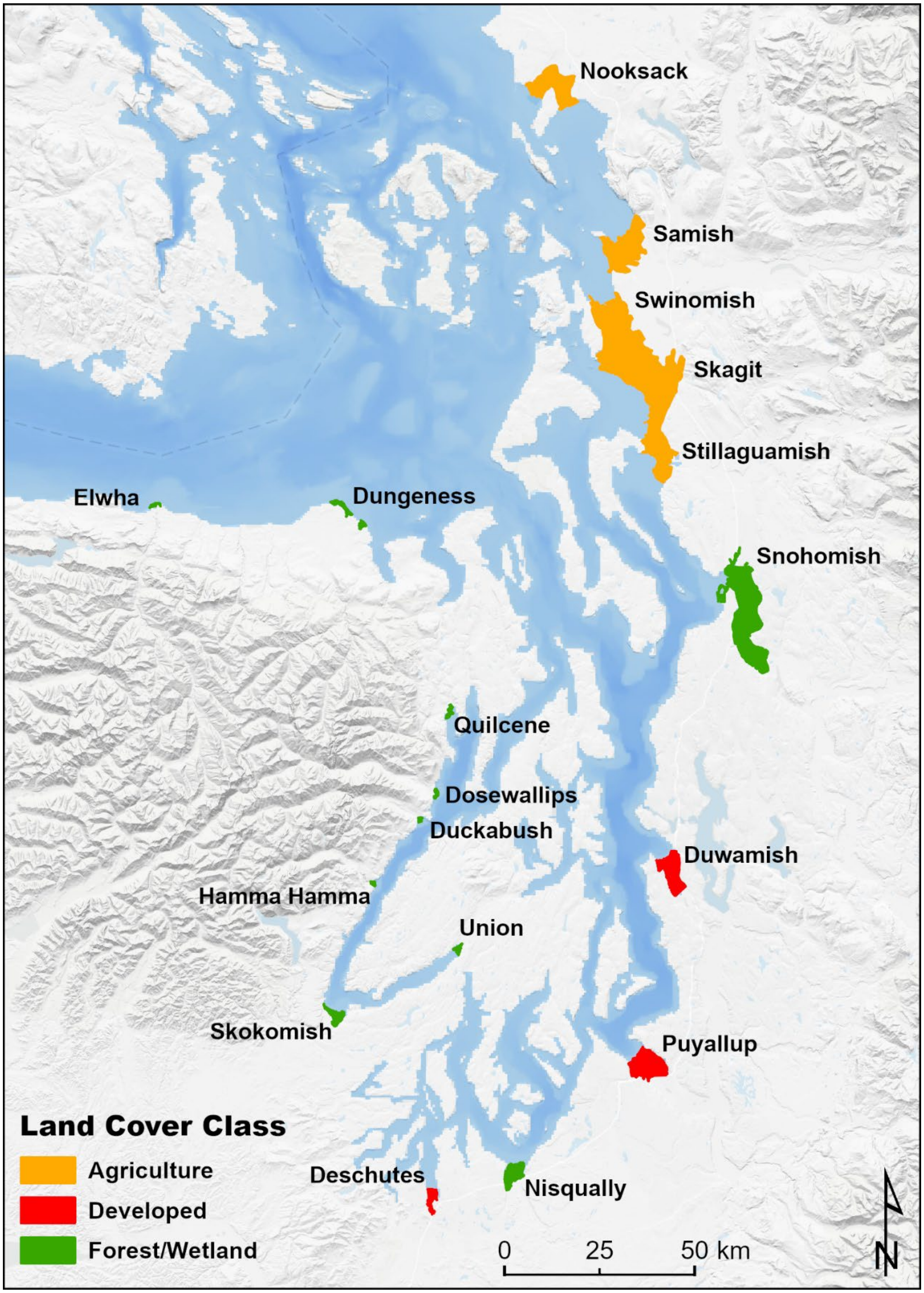


Figure 2. Locations of the 18 major river deltas in Puget Sound.

Delta Habitats

While most deltas changed little between image years, several deltas had significant increases in habitat area accessible to juvenile salmonids due to restoration actions, as well as to natural progradation of deltas. However, some differences were also due to increased imagery resolution, which allowed us to digitize a number of small tidal channels that were not previously visible. We discuss the potential causes of changes in the final section of this report.

Tidal Channel Area

In the Northern Cascades MPG, total habitat areas have increased in the Skagit, Snohomish, and Stillaguamish deltas (Figure 3), and decreased slightly in the Nooksack delta. Most of these increases were due to increased areas of tidal flats (Snohomish) and tidal channel complexes (Skagit, Stillaguamish). The small decrease in the Nooksack delta was mainly the result of lost area of tidal flats and tidal channel complexes.

Habitat areas in three of the South Central Cascades deltas (Duwamish, Puyallup, and Deschutes) are essentially the same in the two time periods (Figure 4). In contrast, the Nisqually delta has lost area of tidal flats as restored areas gradually transition from tidal flats to emergent marsh and tidal channels.

Habitat areas in the Olympic deltas have decreased in five of the eight deltas (Figure 5). The Skokomish and Quilcene both decreased in areas of tidal flats and tidal channel complexes, whereas the Hamma Hamma, Dosewallips, and Duckabush have primarily lost tidal channel complexes. Some of the loss in tidal channel complexes may be due to increased image resolution and conversion from tidal channel complex to tidal channels, which have much smaller areas. Only the Union and Elwha deltas increased in tidal channel area, with the Elwha increasing mainly due to delta progradation since removal of the Elwha dams.

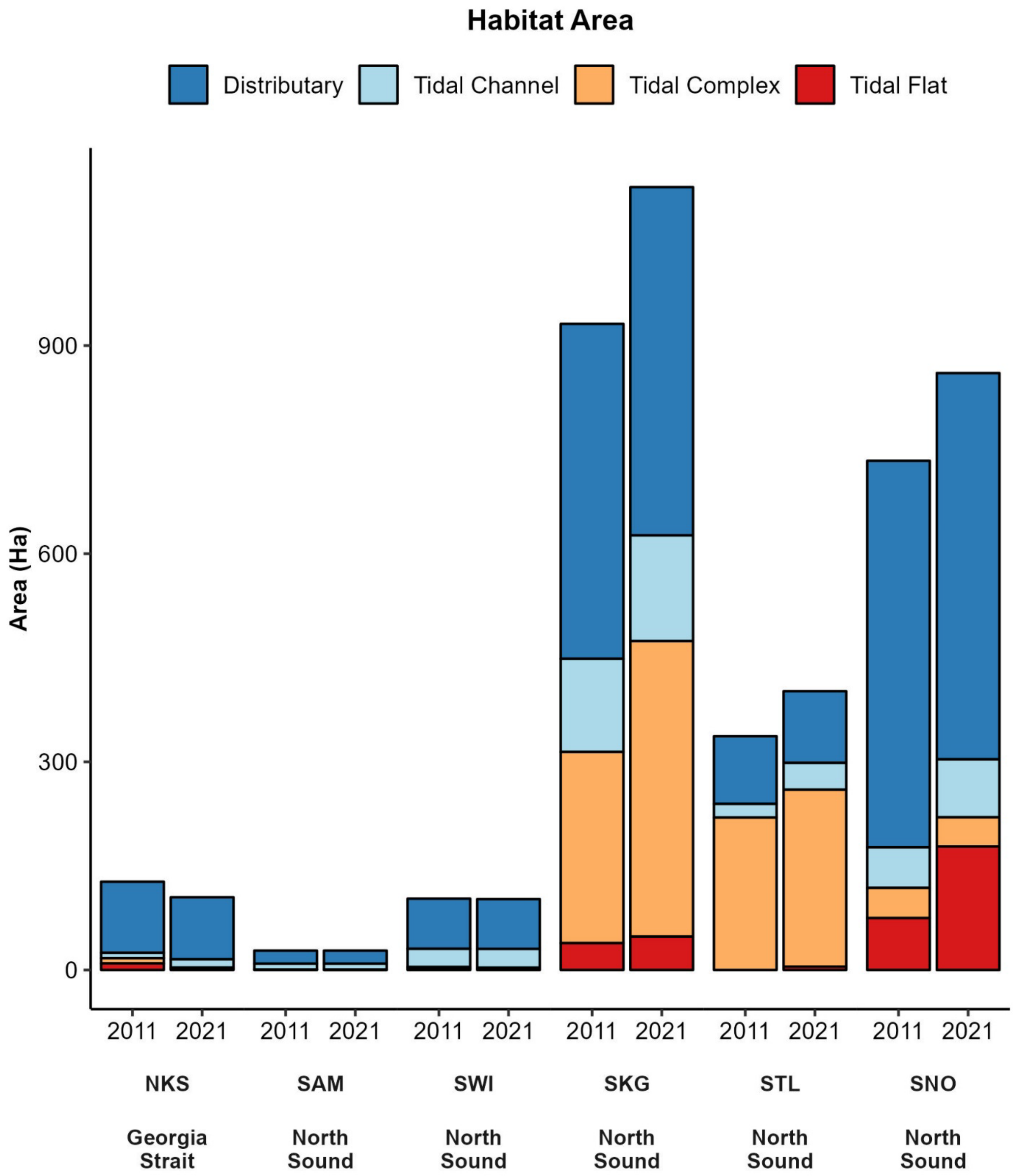


Figure 3. Stacked bar chart of habitat areas with two time periods side-by-side for each delta (Northern Cascades).

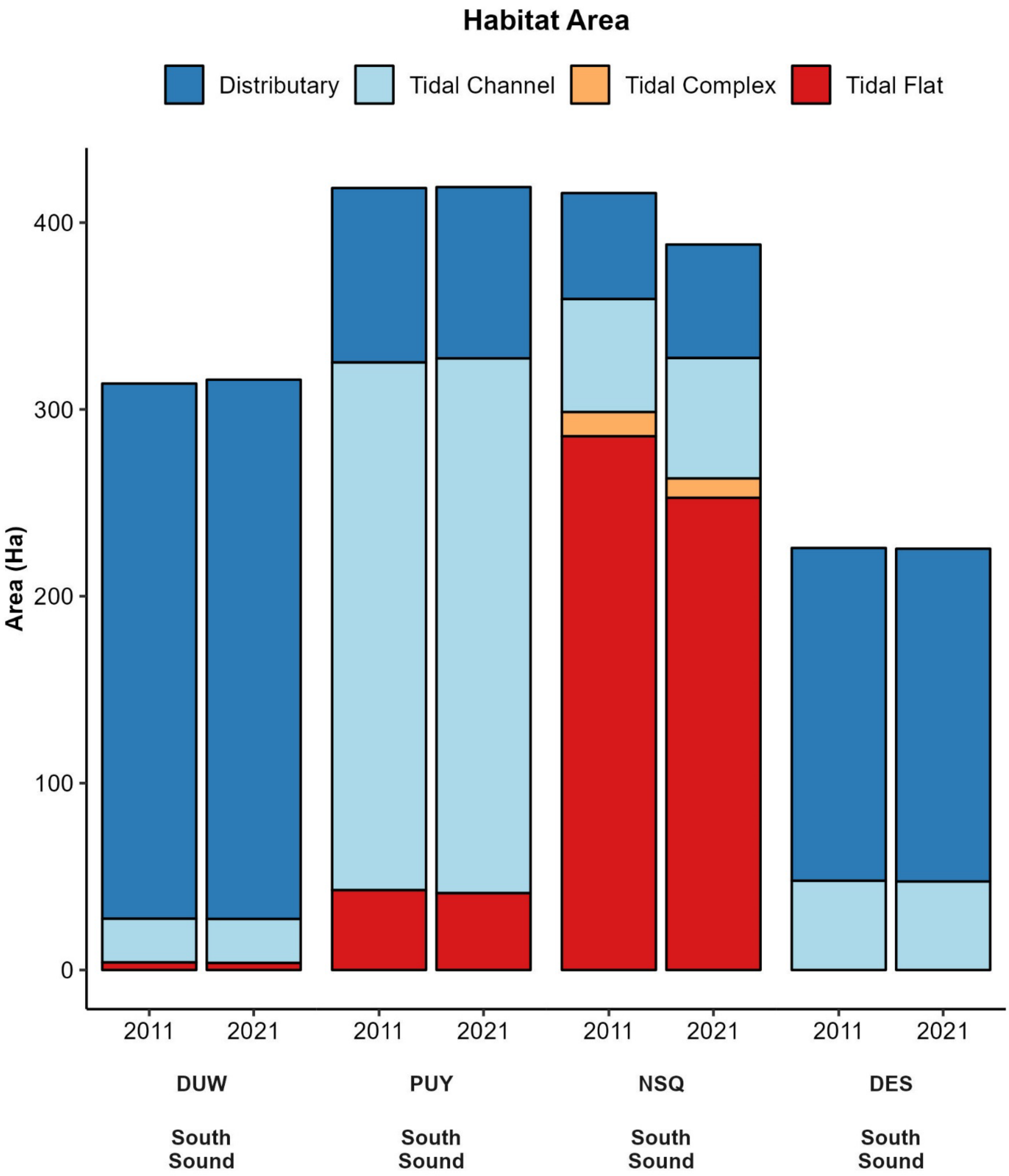


Figure 4. Stacked bar chart of habitat areas with two time periods side-by-side for each delta (South Central Cascades).

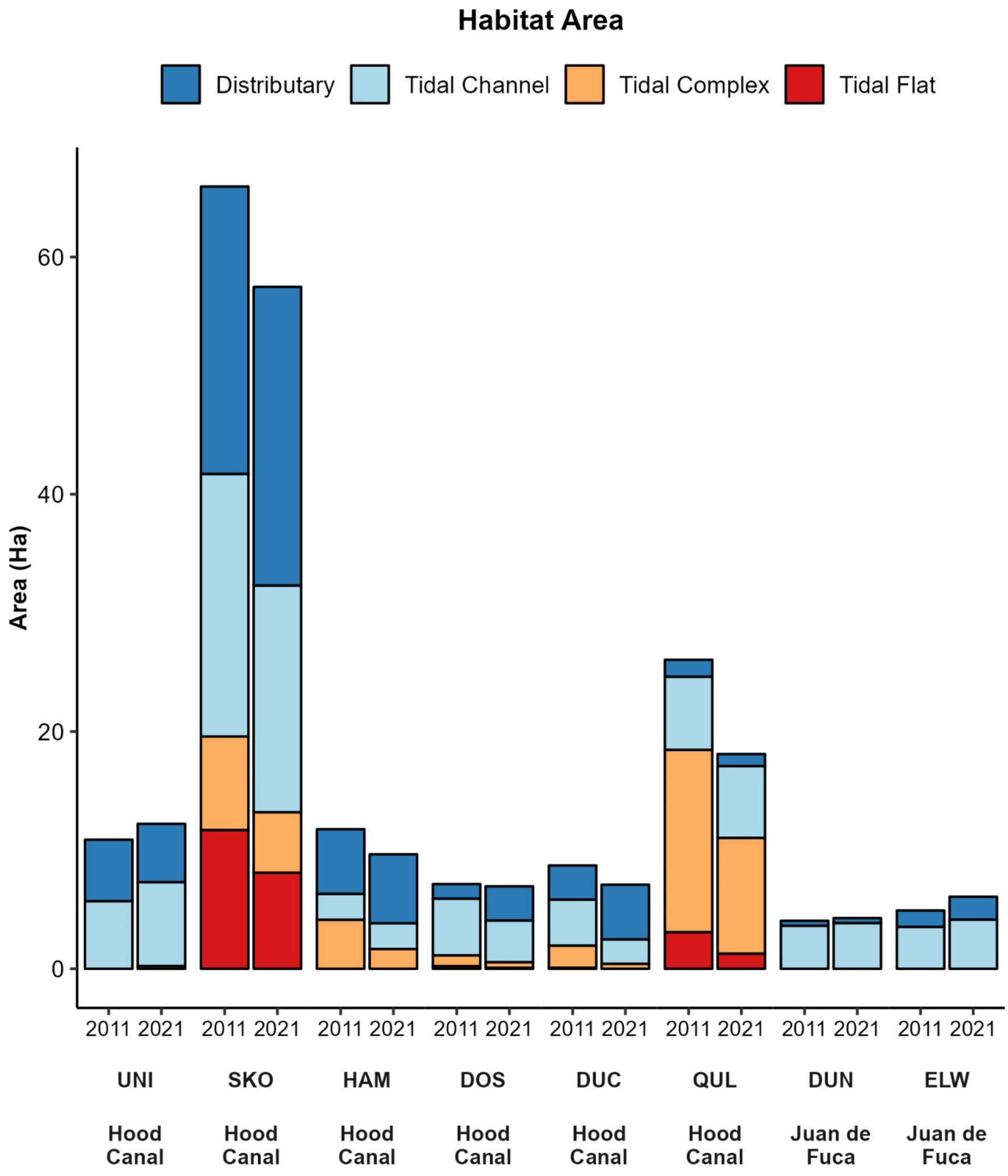


Figure 5. Stacked bar chart of habitat areas with two time periods side-by-side for each delta (Olympic).

Habitat Edge Lengths

In general, the highest densities of rearing juvenile salmon in deltas are near the margins of the various habitat types, so a second useful metric is the total length of edges in each habitat type (Beechie et al. 2017, Stefankiv et al. 2019). In the Northern Cascades MPG, the pattern of edge length change is similar to that of habitat area change (Figure 6), except that habitat edge length in the Nooksack increased while area decreased. Habitat edge length increases were due to increased edge length of tidal flats (Snohomish), tidal channel complexes (Skagit, Stillaguamish), and tidal channels (Nooksack).

As with habitat areas, habitat edge lengths in three of the South Central Cascades deltas (Duwamish, Puyallup, and Deschutes) are essentially the same in the two time periods (Figure 7). However, total edge lengths are much lower in those three deltas compared to the Nisqually delta, whereas total areas of the four were similar (Figure 4). Total habitat edge length in the Nisqually delta increased, primarily as a function of increased edge lengths of tidal flats and tidal channels.

Total habitat edge lengths in the Olympic MPG were relatively similar between the two time periods in six of the eight deltas (Figure 8). Only the Union and Elwha deltas increased in tidal channel edge length, with the Elwha increasing mainly due to delta progradation since removal of the Elwha dams.

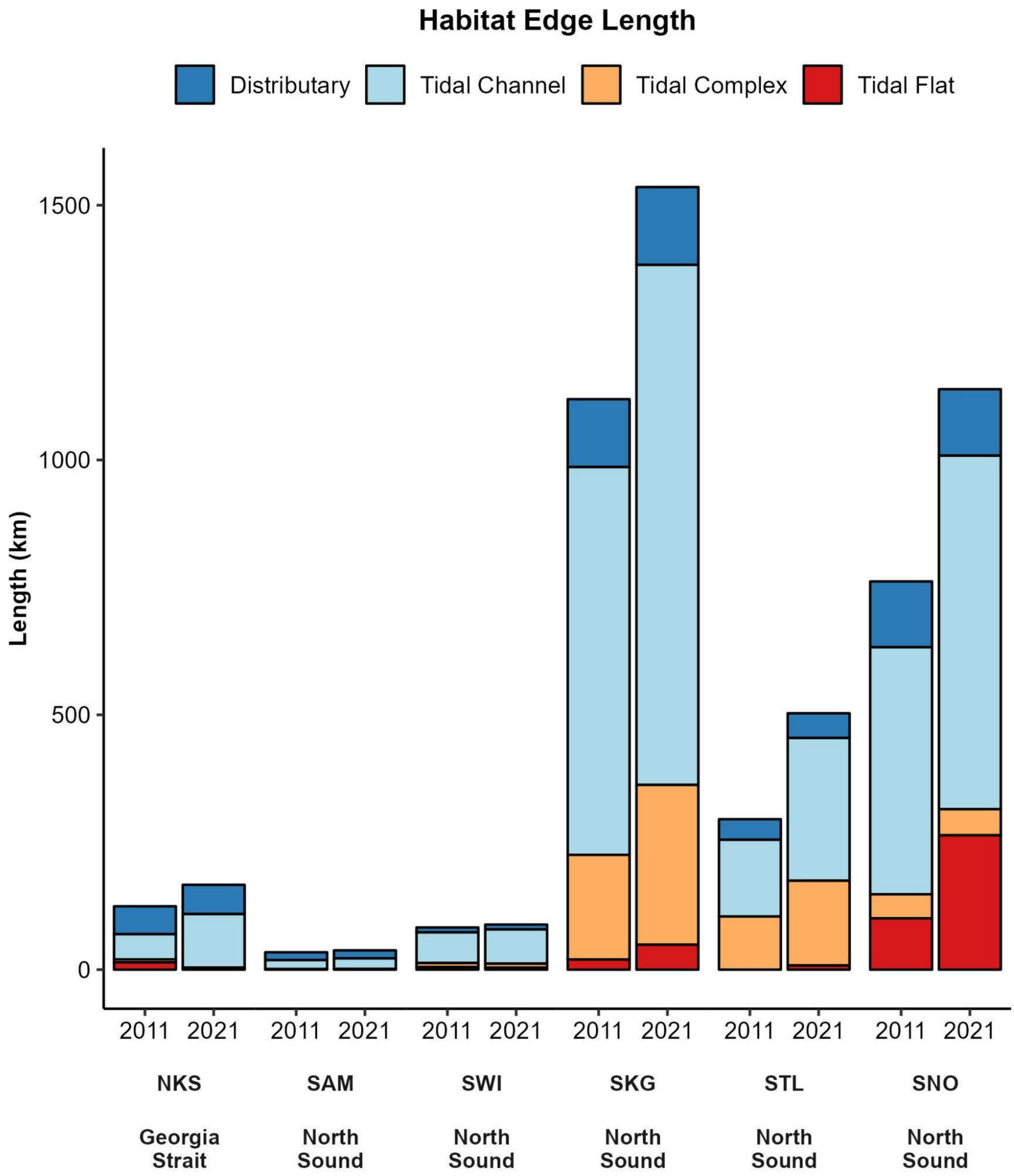


Figure 6. Stacked bar chart of habitat edge length with two time periods side-by-side for each delta (Northern Cascades).

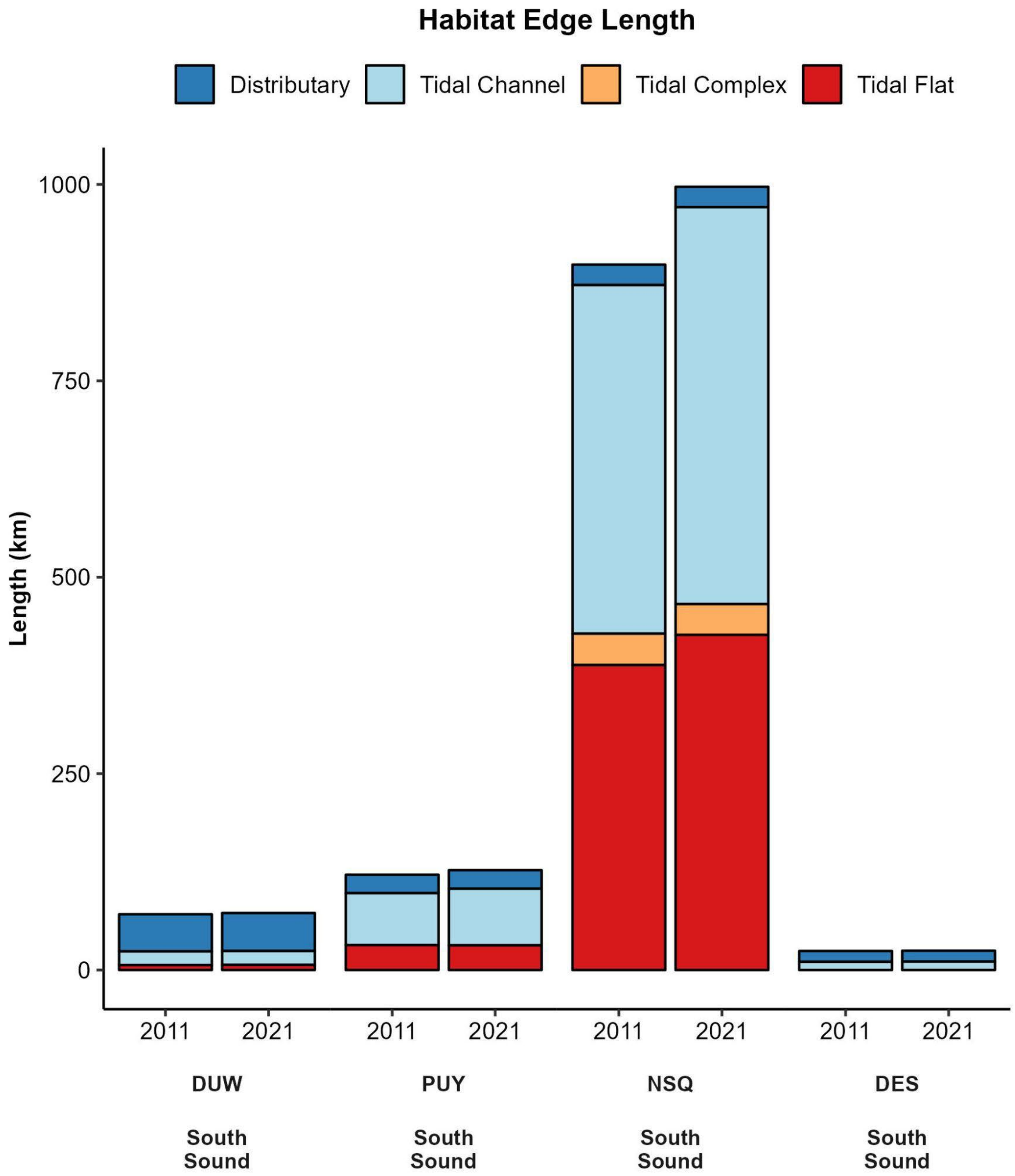


Figure 7. Stacked bar chart of habitat edge length with two time periods side-by-side for each delta (South Central Cascades).

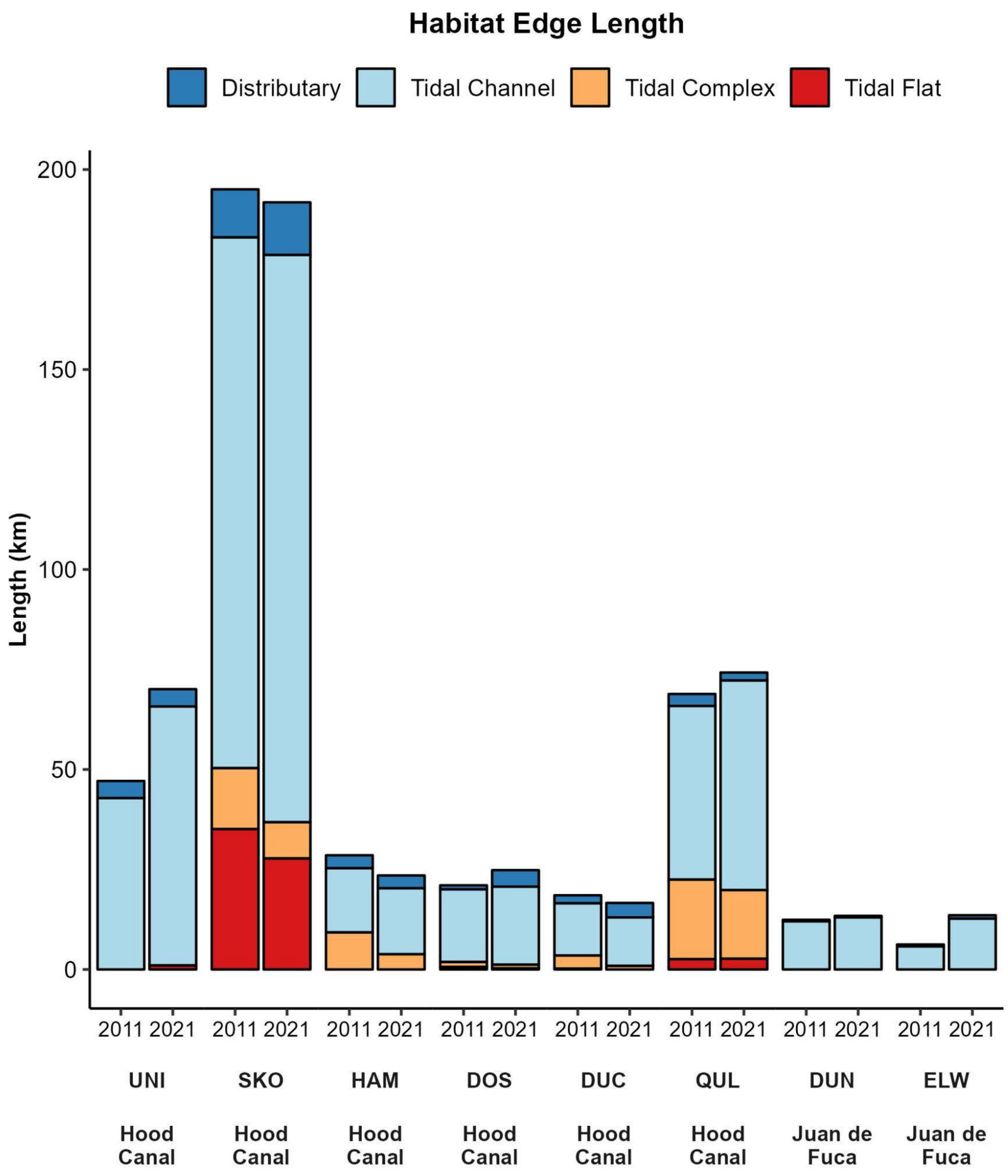


Figure 8. Stacked bar chart of habitat edge length with two time periods side-by-side for each delta (Olympic).

Tidal Channel Length

Only the distributary channels and tidal channels are linear features, so we report channel length (center-line length) for distributary channels and tidal channels but not for tidal channel complexes or tidal flats. In the Northern Cascades MPG, the pattern of channel length change (Figure 9) mirrors that of edge length change. The most notable increases in tidal channel length have occurred in the Nooksack, Skagit, Stillaguamish, and Snohomish deltas, where recent restoration has taken place. Channel length increases were primarily due to increased tidal channel length in all cases.

As with habitat edge lengths, channel lengths in three of the South Central Cascades deltas (Duwamish, Puyallup, and Deschutes) are essentially the same in the two time periods, whereas total channel length in the Nisqually delta increased (Figure 10). Moreover, total edge lengths are much lower in those three deltas compared to the Nisqually delta. Total channel lengths in five of the eight deltas in the Olympic MPG increased between the two time periods (Union, Skokomish, Dosewallips, Quilcene, Elwha) (Figure 11).

Across all Puget Sound deltas, total distributary and tidal channel lengths are highest in the three largest deltas (Skagit, Snohomish, and Nisqually), and increases in all three channels were a combination of restored and naturally created habitats (Figure 12). Most of the Nisqually restoration occurred prior to our first survey, so the increase in channel length due to restoration between the two time periods is relatively small. The increases due to restoration in the Skagit (~2x) and Snohomish (~4x) deltas are substantial, and the Stillaguamish delta had virtually no restored channel length in 2011 and its restored length is now nearly equal to that of the Skagit. Changes in most of the other deltas are very small by comparison.

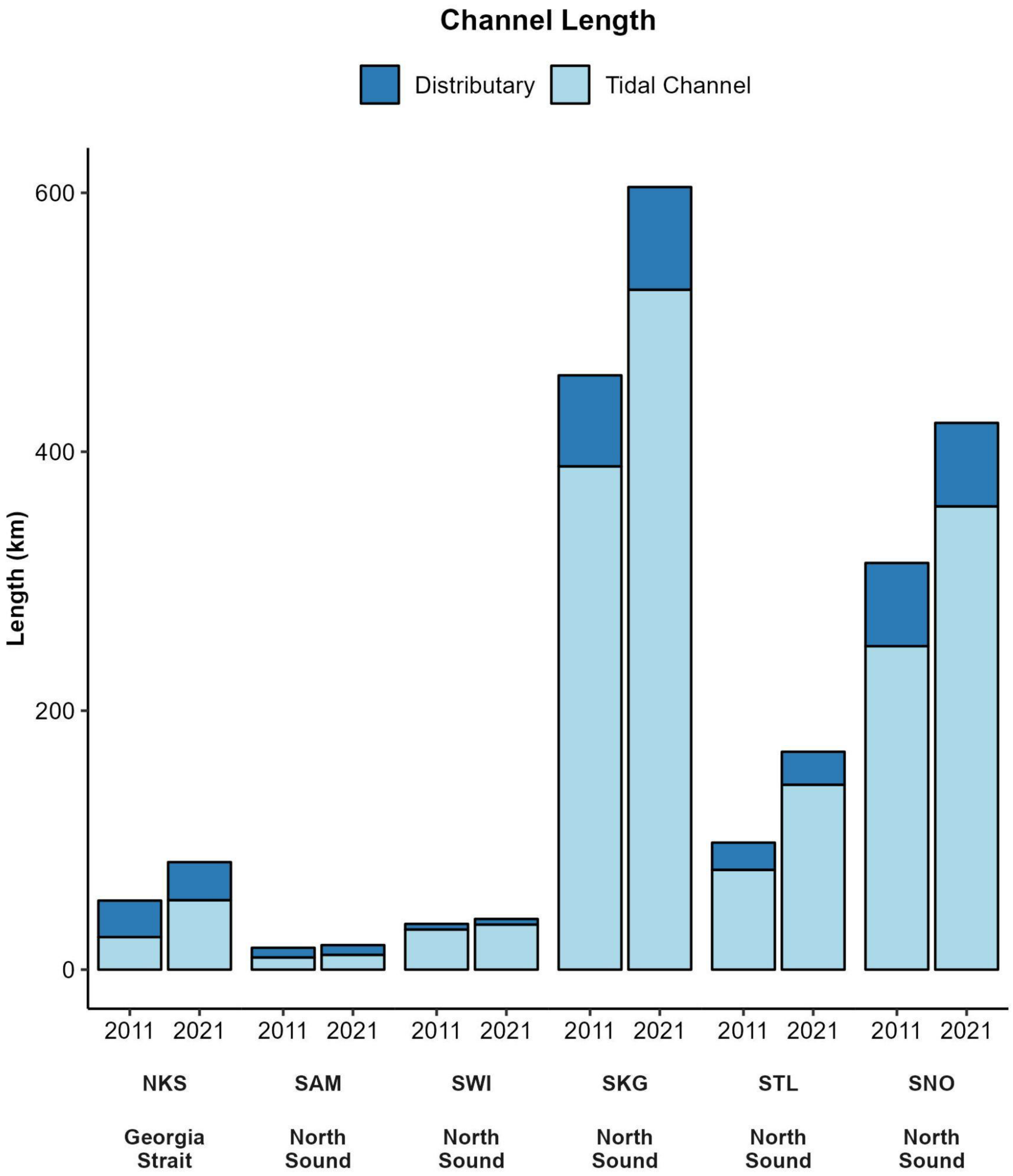


Figure 9. Stacked bar chart of delta channel length with two time periods side-by-side for each delta (Northern Cascades).

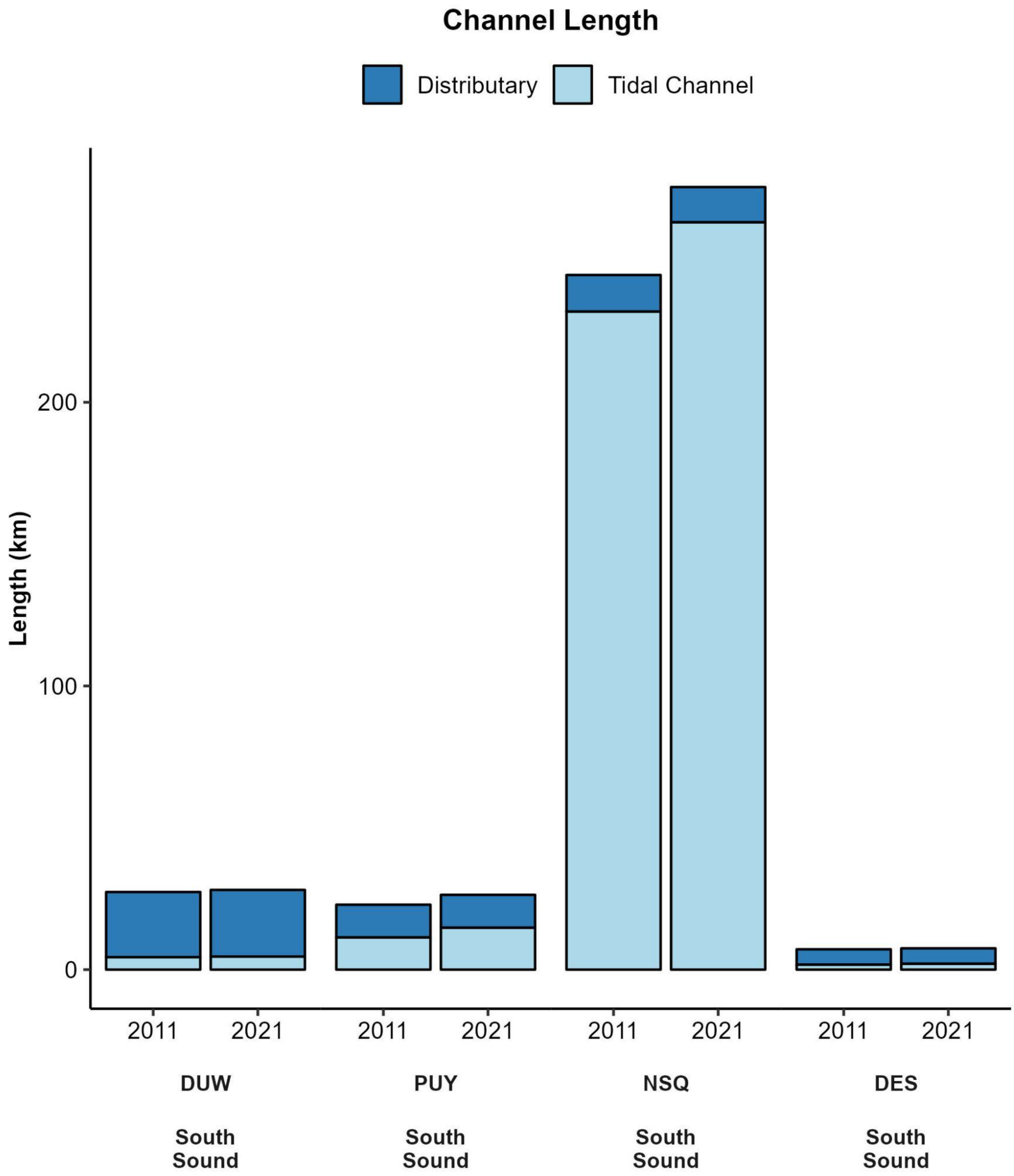


Figure 10. Stacked bar chart of delta channel length with two time periods side-by-side for each delta (South Central Cascades).

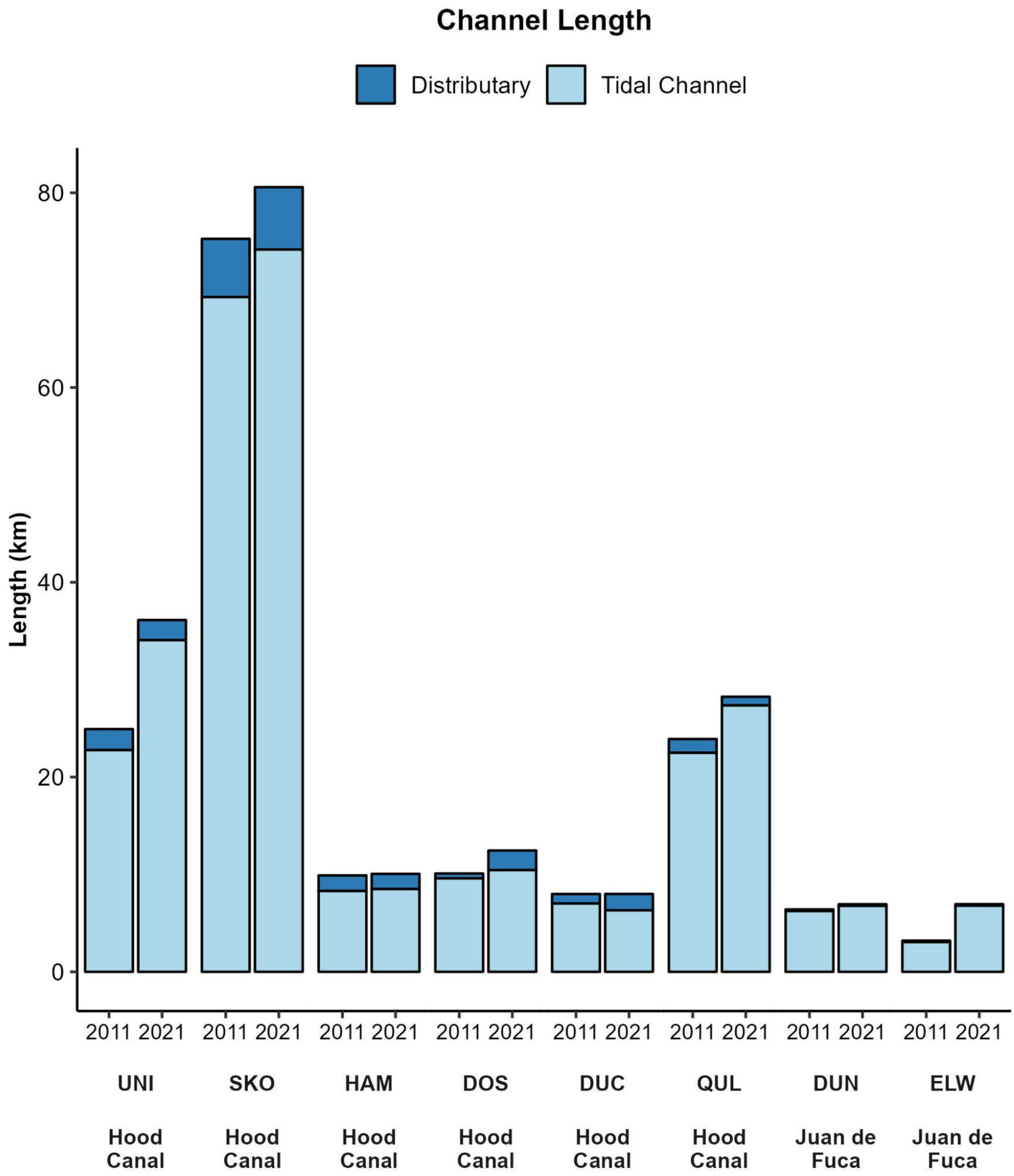


Figure 11. Stacked bar chart of delta channel length with two time periods side-by-side for each delta (Olympic).

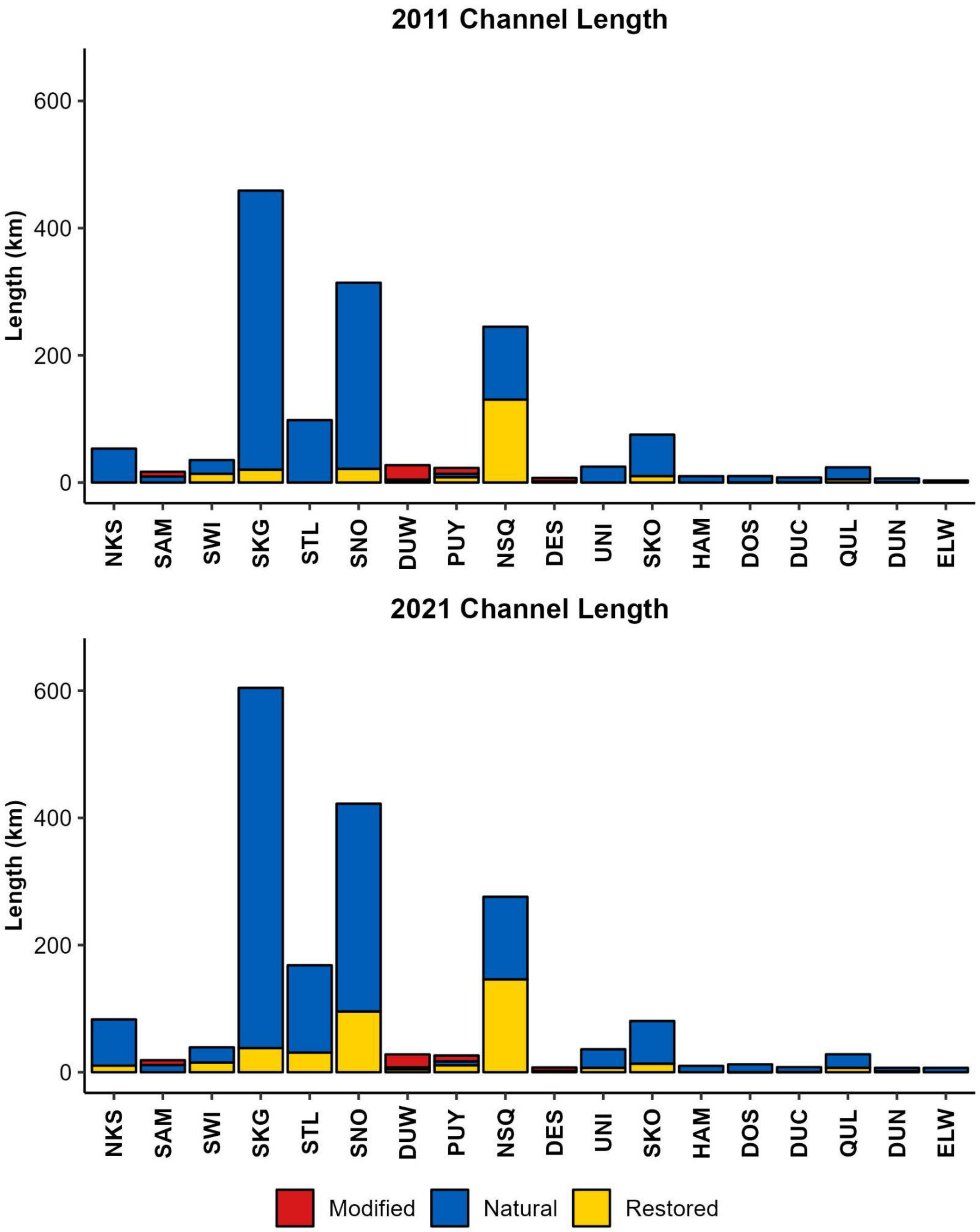


Figure 12. Stacked bar chart of delta channel length by type with two time periods for each delta.

Node Density

The density of tidal channel connections relative to total primary distributary channel length (node density) increased in most deltas between imagery years (Table 3). However, we believe that some of this difference is due to imagery resolution (see Discussion). Nonetheless, most of the changes appear to be from natural changes or restoration actions.

Table 3: Channel node density relative to the total length of primary distributary channels in the two time periods by delta and MPG (Steelhead MPGs = North Cascades, Olympic, and South Central Cascades; Chinook MPGs = Georgia Strait, North Sound, Hood Canal, Juan de Fuca, and South Sound. NKS = Nooksack, SAM = Samish, SWI = Swinomish, SKG = Skagit, STL = Stillaguamish, SNH = Snohomish, QUL = Big Quilcene, DOS = Dosewallips, DUC = Duckabush, HAM = Hamma Hamma, SKO = Skokomish, UNI = Union, DUN = Dungeness, ELW = Elwha, DUW = Duwamish, PUY = Puyallup, NSQ = Nisqually, and DES = Deschutes. Node density within the Swinomish delta was not calculated due to absence of a primary distributary.

Steelhead MPG **Chinook MPG** Delta	**Channel Node Density (nodes/km of primary distributary)**	
	Period 1 (2010-12)	**Period 2 (2017-21)**
Northern Cascades	**461.5**	**781.7**
Georgia Strait	**90.4**	**224.5**
NKS	90.4	224.5
North Sound	**105.1**	**871.0**
SAM	45.5	68.9
SWI	**	**
SKG	1199.1	2184.0
STL	655.6	1305.0
SNH	441.1	637.1
Olympic	**760.4**	**1014.6**
Hood Canal	**774.9**	**1016.4**
QUL	2051.8	2558.9
DOS	1013.9	1561.6
DUC	329.2	348.8
HAM	454.6	511.5
SKO	846.0	1106.4
UNI	726.2	899.5
Juan de Fuca	**431.8**	**975.0**
DUN	587.4	880.6
ELW	256.5	1075.2
South Central Cascades	**240.7**	**335.4**
South Sound	**240.7**	**335.4**
DUW	4.3	4.6
PUY	27.6	44.3
NSQ	2335.5	3240.4
DES	6.9	15.2
Total	**396.0**	**619.8**

Overwater Structures

We summarized overwater structures by Puget Sound Marine Basin (Figure 13) rather than MPG because juvenile salmonids from multiple river basins and MPGs can use the same shoreline habitat areas. We found that the greatest *number* of overwater structures were in South Central Puget Sound and in Hood Canal (Figure 14), whereas the greatest *change* in the number of OWSs between time periods occurred in the Hood Canal and Whidbey Marine Basins. The number of OWSs increased in Hood Canal between the 2013-2016 and 2021-2022 time periods, while the number of OWSs decreased in the Whidbey Marine Basin.

While the *number* of OWSs in Hood Canal is comparatively higher than it is in other Marine Basins, the OWS *area* in Hood Canal is comparable to that of the other basins (Figure 15). The area of overwater structures is greatest in the South Central Puget Sound where many of the large structures, such as ports, ferry terminals, and aquaculture are more common than in other marine basins. The largest change in OWS area between time periods were decreases in OWS area in the Whidbey and Strait of Juan de Fuca Basins.

We also summarized associations between adjacent land cover and the number and area of overwater structures. We found a greater number of structures per kilometer along shorelines that are dominated by developed land cover (Figure 16), while the lowest number of structures per kilometer is along shorelines classified as agriculture. Shorelines along agricultural lands often lack the private and commercial development present along other shorelines that lead to increased presence of marine overwater structures. Overall, there was very little change in the number of overwater structures between the two surveyed time periods (2013-2016 and 2021-2022), but there was a slight increase in the number of OWS along forested and mixed land cover shorelines and a small decrease along developed shorelines (Figure 14, Appendix A). The number of OWS remained similar along shorelines dominated by the agriculture land cover class.

We found a similar rank order of OWS *areas* per kilometer of shoreline among the four land cover classes, although differences between land cover strata were larger than for the number of OWSs. The largest OWS area per kilometer is along developed shorelines (Figure 17), especially at ports and ferry terminals where large piers and docks tend to be significantly larger than private structures such as small docks and floats. OWS area per kilometer in all other land cover classes is less than a third of that of developed shorelines, with the lowest area along agricultural lands.

It is worth noting that the number of OWSs in the Hood Canal Marine Basin is very high despite its adjacent land cover being predominantly forest (Figure 18), while the OWS area in the Hood Canal Marine Basin is relatively low. This is likely because there are many small private residential docks and floats. In contrast, in the South Central Puget Sound both the number and area of OWSs are high, indicating that where the percentage of developed land cover is high, there are likely both many small docks and concentrations of a few large piers (e.g., in Seattle, Tacoma, and Olympia).

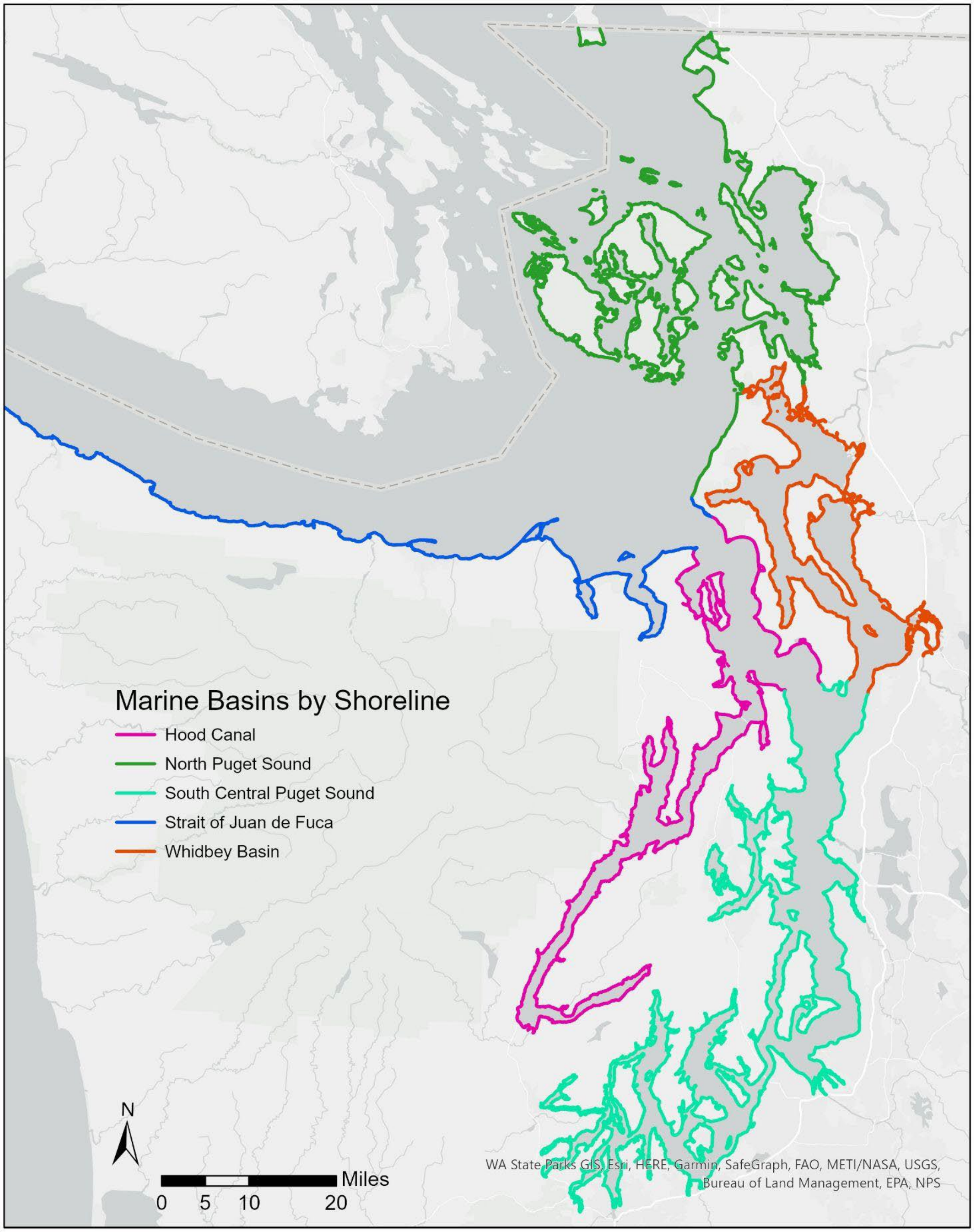


Figure 13. Map of shoreline lengths included in each Marine Subbasin.

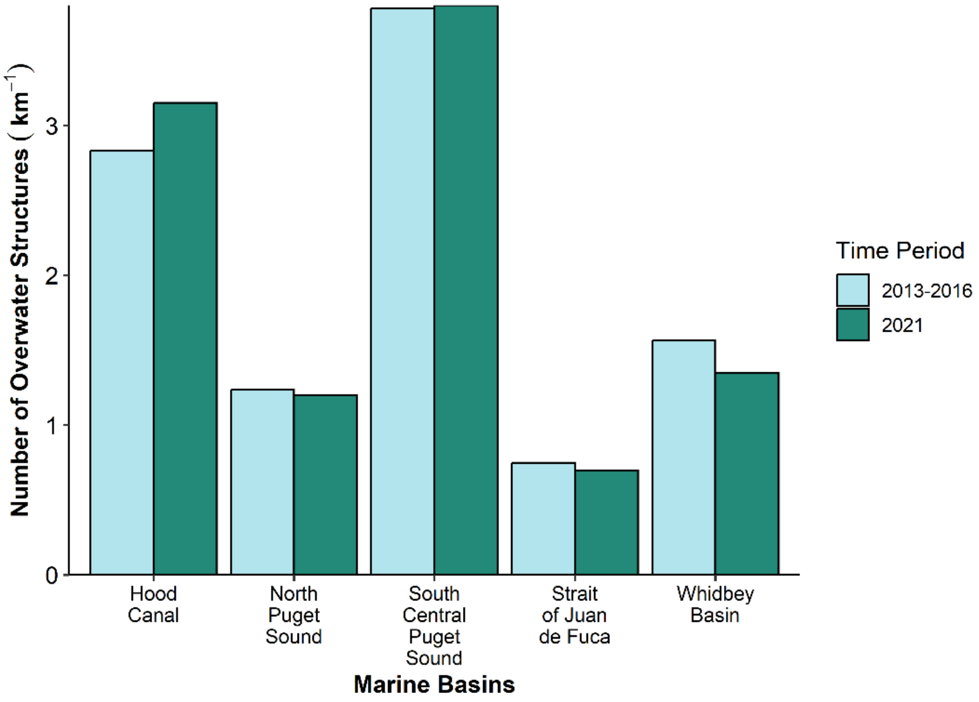


Figure 14: Number of Overwater Structures by Marine Basin.

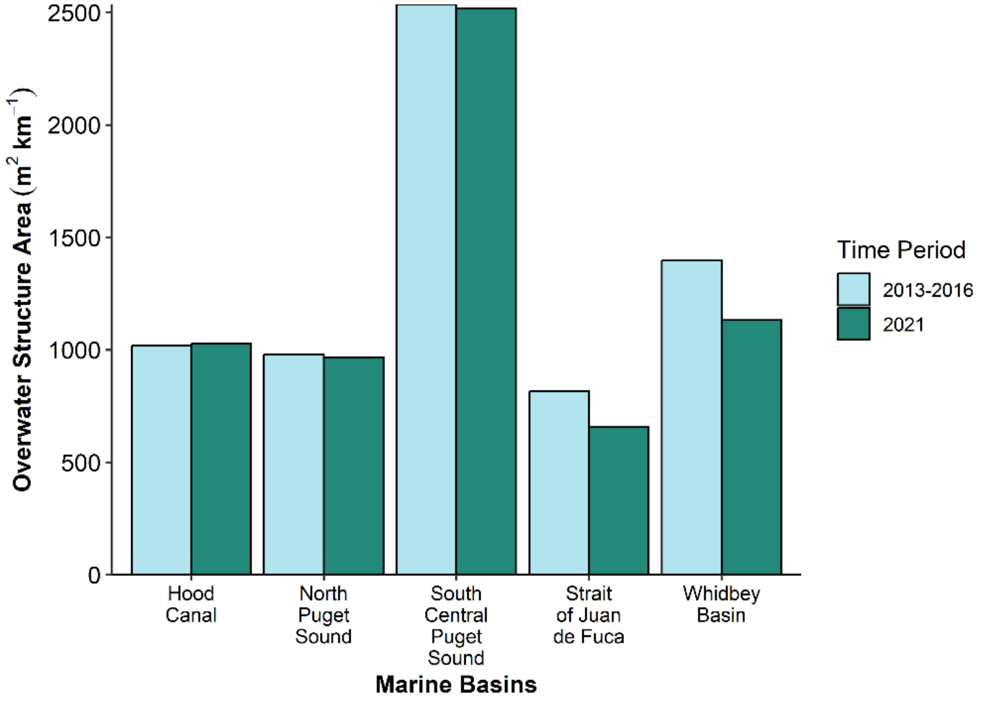


Figure 15: Area of Overwater Structures by Marine Basin.

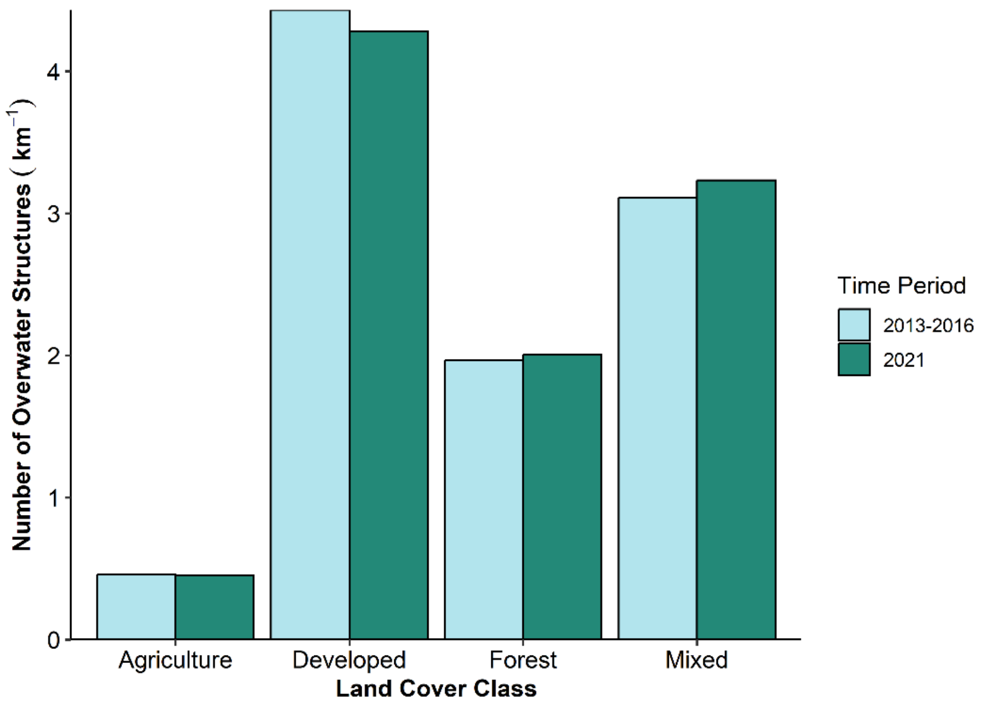


Figure 16: Number of Overwater Structures by Land Cover Class.

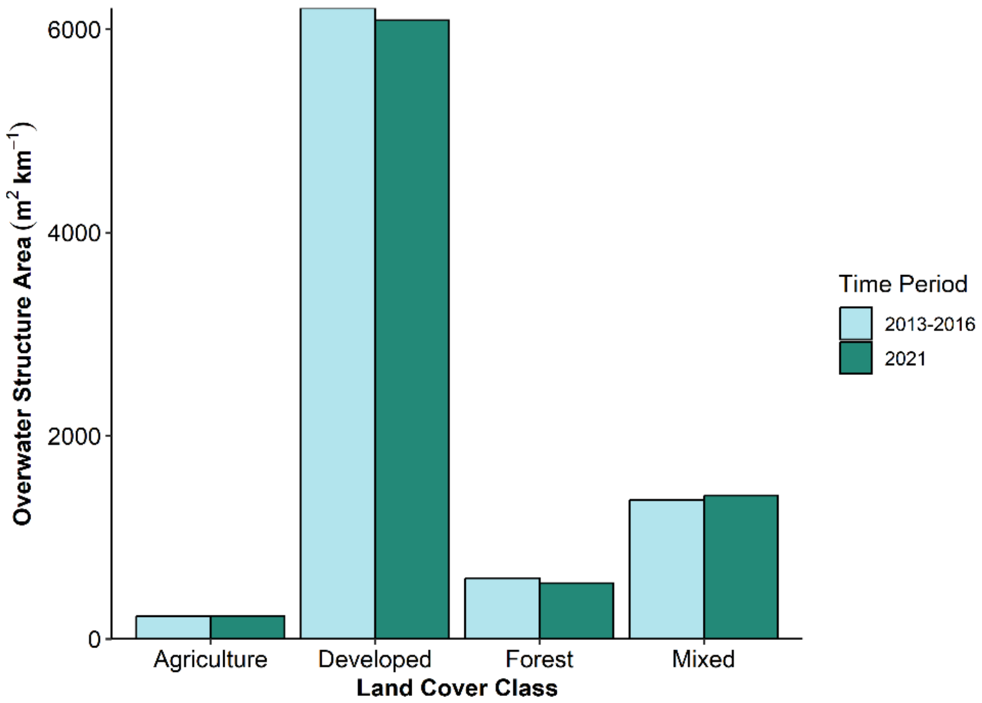


Figure 17: Area of Overwater Structures by Land Cover Class.

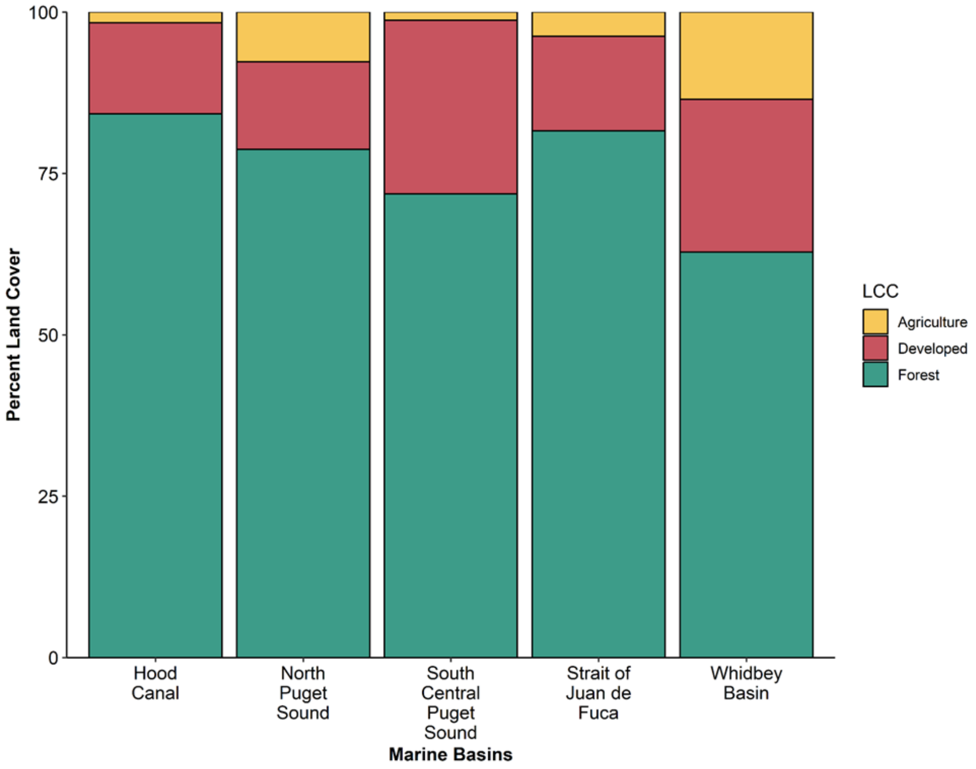


Figure 18: Percent of Land Cover Class by length of shoreline by Marine Basin.

To better understand the declines in area of overwater structures in the Strait of Juan de Fuca and Whidbey Marine Basins (Figure 15), we also examined gains and losses of structure area by structure type and marine basin (Figures 19-24). We found that gains roughly offset losses in the Hood Canal, North Puget Sound, and South Central Puget Sound Marine Basins, so there was very little change between 2013-2016 and 2021-2022. In contrast, decreased areas were larger than increases in the Strait of Juan de Fuca and Whidbey Marine Basins, resulting in overall declines in OWS areas in those basins. In the Strait of Juan de Fuca Marine Basin decreases were mostly in areas of log booms and aquaculture, whereas in the Whidbey Marine Basin, decreases were mostly in areas of log booms and docks/piers.

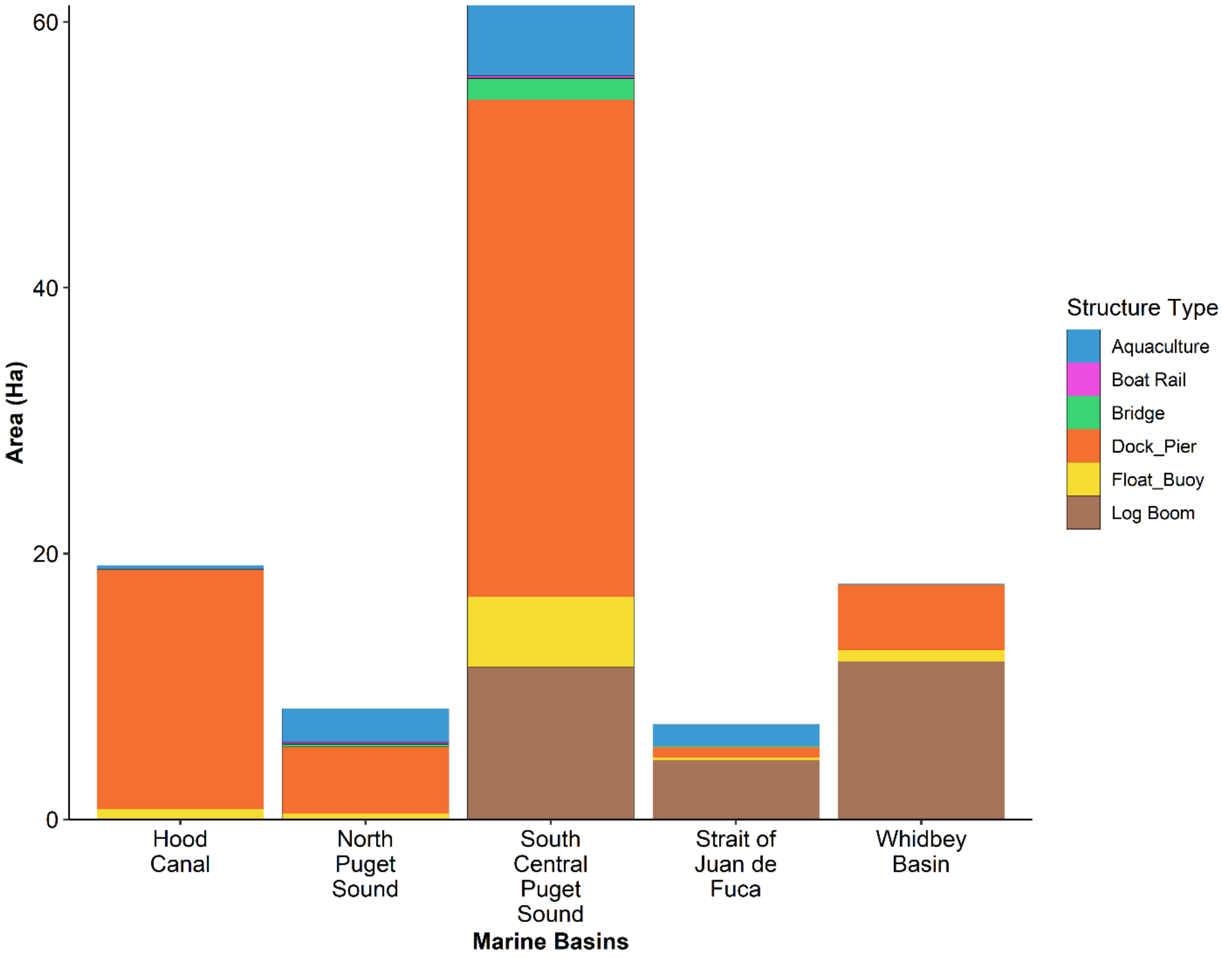


Figure 19. Area of removed or moved overwater structures by structure type and Marine Basin (all structure types).

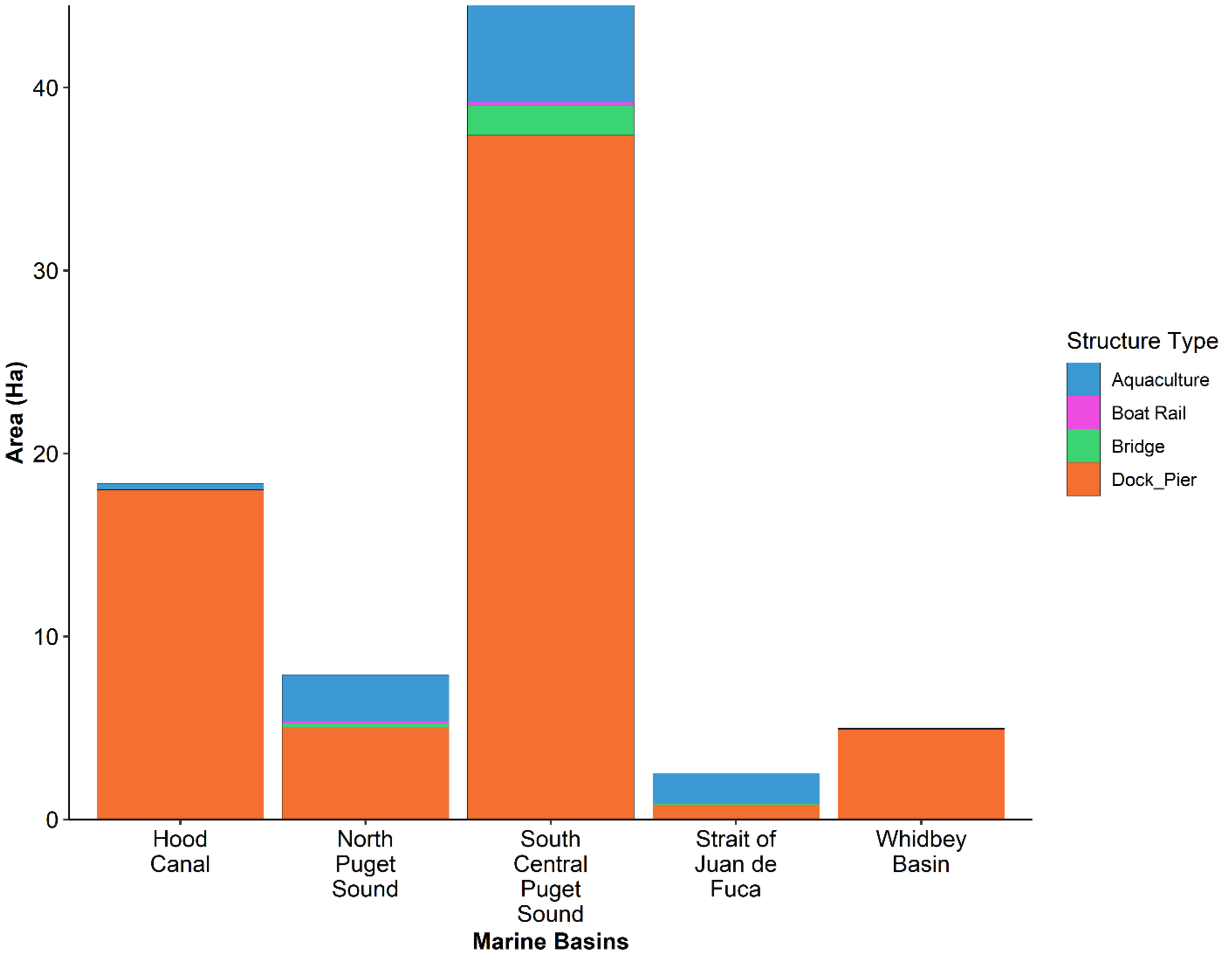


Figure 20. Area of removed or moved overwater structures by structure type and Marine Basin (stationary structures only). Aquaculture includes only netpens.

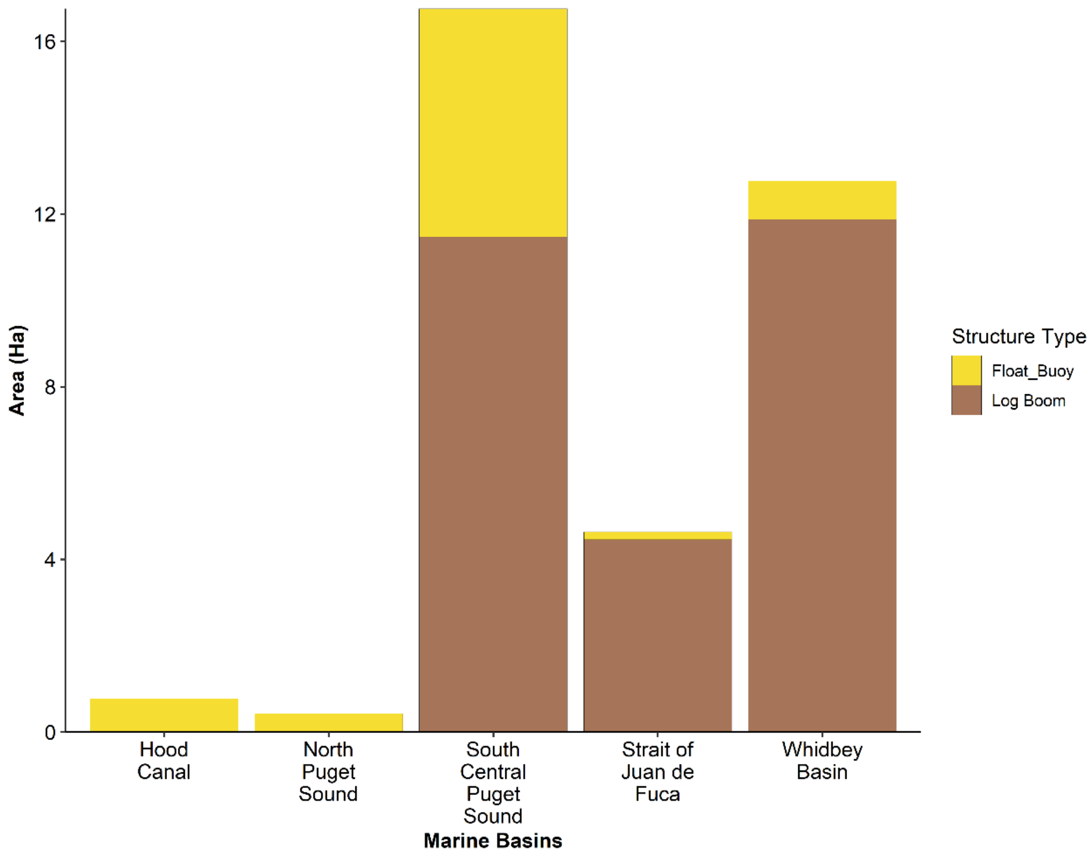


Figure 21. Decrease in overwater structure area by structure type and Marine Basin (moveable structures only).

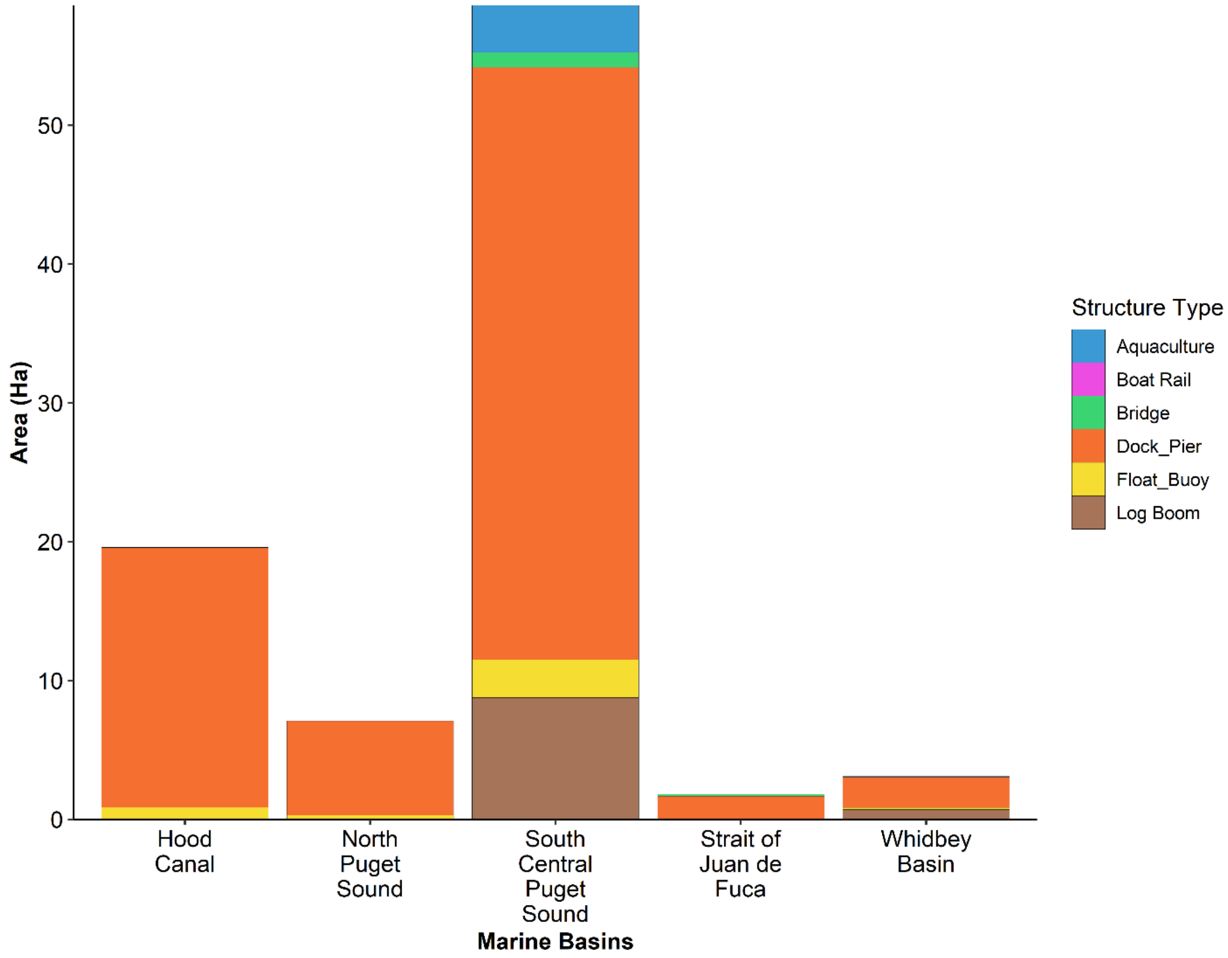


Figure 22. Increase in overwater structure area by structure type and Marine Basin (all structure types).

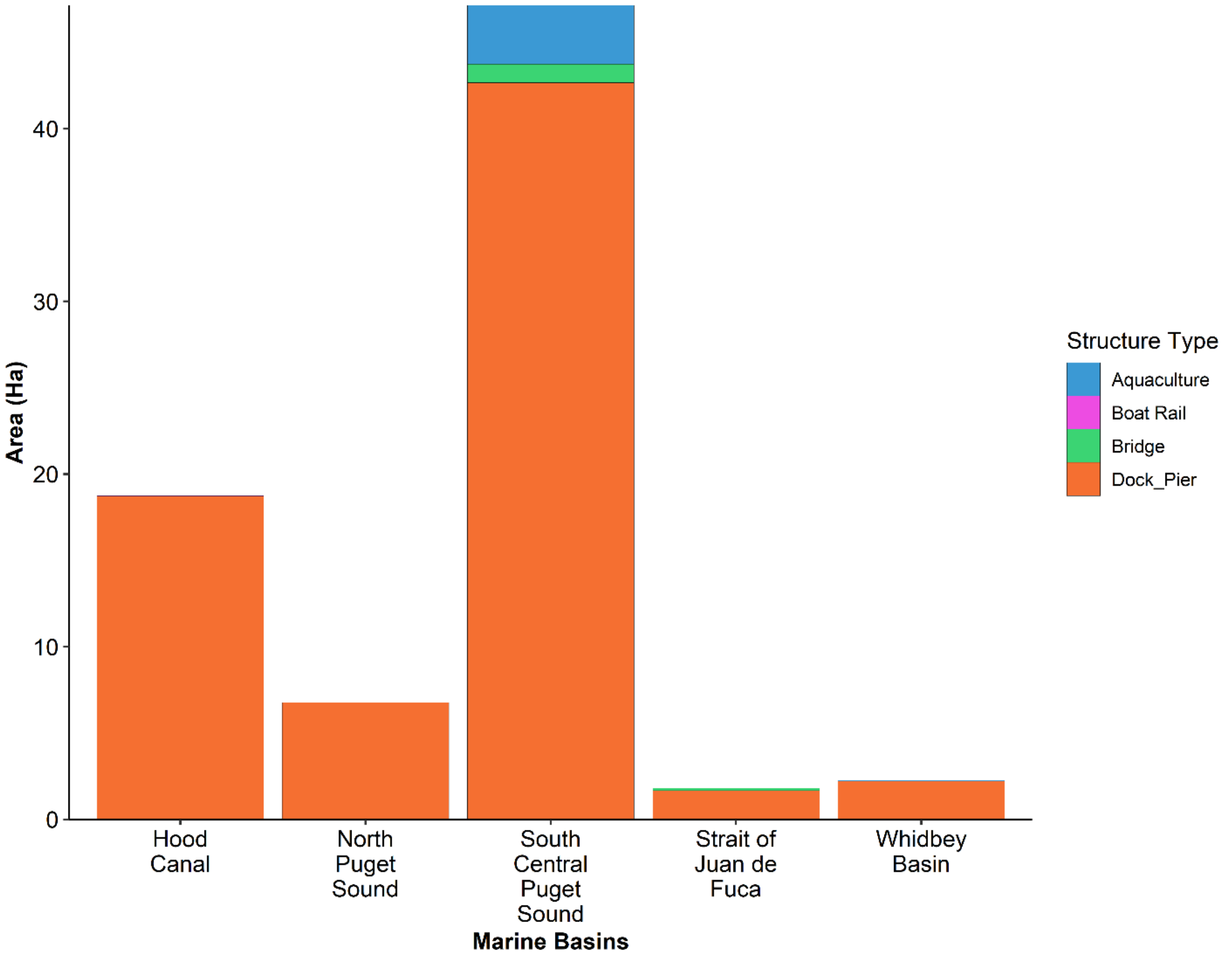


Figure 23. Increase in overwater structure area by structure type and Marine Basin (stationary structures only). Aquaculture includes only netpens.

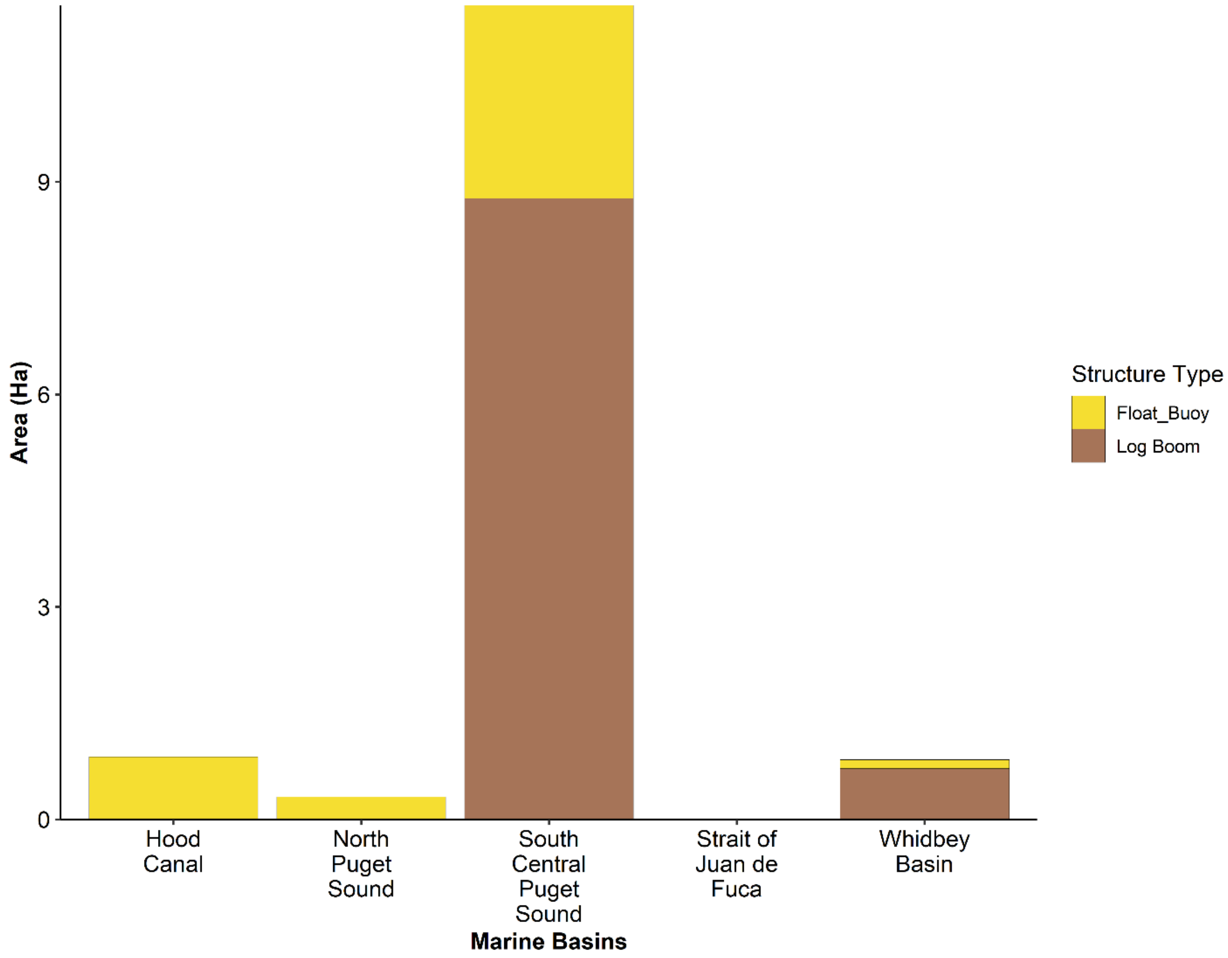


Figure 24. Increase in overwater structure area by structure type and Marine Basin (moveable structures only).

Discussion

Delta Habitats

We originally adopted the node density metric based on studies of river habitat (Whited et al. 2013), with less support from studies of river deltas (Beamer et al. 2005). In retrospect, node density per kilometer of main distributary length is largely a function of a delta's width relative to its length. For example, node density per km is relatively low in the Snohomish basin (which is very long with limited tidal channels), whereas it is quite high in the much smaller Quilcene delta (which is much wider than it is long). This means that comparisons across deltas may not be meaningful, although changes within any single delta should be a reliable indicator of the trend within it.

It is clear that the selected metrics provide different views of the status of delta habitats, so we offer four suggestions for interpretation of the results.

1. Habitat area is the most appropriate metric for tidal channel complexes, which are not linear features. Functional edge habitats within tidal complexes are in the network of channels within the complex, so a linear measure of the edge length of a tidal channel complex is not a meaningful habitat metric.
2. Tidal flats are also not linear features, although the edge of a tidal flat is useable habitat and both the habitat area and habitat edge length are useful metrics.
3. Distributary channels and tidal channels are linear features, and useable habitat is typically along the edges of each channel. The center of distributaries in particular is often not suitable salmonid habitat, so the most useful metrics for distributary and tidal channels are the length and edge length metrics, but not the area metric.
4. Node density is ostensibly a measure of the delta habitat complexity, although the total number of nodes is largely a function of delta size and the node density is a function of delta width relative to delta length. Node density does not appear to be a useful metric for comparisons among deltas, but it may be useful for comparisons among time periods within each delta.

It is important to note that in some cases, the apparent reduction of tidal complex areas in deltas is due to higher spatial (30 cm vs 15 cm) and spectral (true-color vs false-color) resolution imagery in the 2017-2021 time period, which allowed us to see more small tidal channels that were visible in the 2010-2012 imagery. Therefore, some areas that we previously digitized as tidal channel complexes were removed and replaced with a network of digitized small tidal channels. This means that some increases in tidal channel length (but not distributary length) are also attributable to increased imagery resolution. While we did not quantify the amount of change attributed to imagery resolution, we believe it is a small amount compared to habitat changes due to either natural delta progradation or delta restoration actions.

Overwater Structures

The metrics for overwater structures are generally straightforward, as number and area of overwater structures together help illustrate the types of shoreline impacts captured in the inventory. For example, the fact that the Hood Canal Marine Basin has a very high number of OWSs but a relatively small area indicates that this basin has a large number of small, recreational docks and floats. In contrast, the South Central Puget Sound Marine Basin has both a large number and large area of OWSs, indicating the presence of both many small docks and a number of large docks and piers in urban areas such as Seattle, Tacoma, and Olympia.

We note that some categories of OWS may be less meaningful than others, most notably the floats category. We observed that floats often vary significantly in number and location over periods of months to years (based on sequential imagery in Google Earth), so any snapshot in time may not represent the dominant condition within a year. Other more permanent structures, such as docks and piers, typically remain in place for years, and they likely give us a better indication of time trends in overwater structure number and area.

While an increase in OWS area is generally considered a negative, there are special cases where an increase in area can have a positive impact, for example the replacement of a culvert for a bridge. In these cases, the change would be noted by an increased area of a particular OWS (e.g., Gibson Spit near Port Williams). However, these cases are rare compared to instances of either the removal or construction of docks and piers.

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Appendix A. Tabular Results

Table A-1. Area (hectares) of channel features by delta and MPG in time period 1 (2010-2012). Steelhead MPGs = North Cascades, Olympic, and South Central Cascades; Chinook MPGs = Georgia Strait, North Sound, Hood Canal, Juan de Fuca, and South Sound. Deltas are NKS = Nooksack, SAM = Samish, SKG = Skagit, STL = Stillaguamish, SNH = Snohomish, QUL = Big Quilcene, DOS = Dosewallips, DUC = Duckabush, HAM = Hamma Hamma, SKO = Skokomish, UNI = Union, DUN = Dungeness, ELW = Elwha, DUW = Duwamish, PUY = Puyallup, NSQ = Nisqually, and DES = Deschutes.

Steelhead MPG, Chinook MPG, Delta	Distributary Area (ha)	Tidal Channel Area (ha)	Tidal Complex Area (ha)	Tidal Flat Area (ha)	Total Area (ha)
Northern Cascades	**1331.2**	**255.2**	**549.4**	**124.7**	**2260.4**
Georgia Strait	**102.5**	**7.7**	**7.7**	**9.3**	**127.2**
NKS	102.5	7.7	7.7	9.3	127.2
North Sound	**1228.7**	**247.5**	**541.7**	**115.3**	**2133.2**
SAM	18.9	8.5	0.3	0.3	28.0
SWI	72.3	26.3	2.8	1.5	102.9
SKG	482.8	134.3	275.5	38.7	931.3
STL	97.6	19.7	219.7	0.0	336.0
SNH	557.1	58.6	43.4	74.9	734.0
Olympic	**42.2**	**52.0**	**30.2**	**15.1**	**139.5**
Hood Canal	**40.4**	**44.8**	**30.2**	**15.1**	**130.5**
QUL	1.4	6.2	15.4	3.1	26.1
DOS	1.2	4.8	0.9	0.2	7.1
DUC	2.9	3.9	1.9	0.1	8.8
HAM	5.5	2.2	4.1	0.0	11.8
SKO	24.2	22.1	7.9	11.7	65.9
UNI	5.2	5.7	0.0	0.0	10.9
Juan de Fuca	**1.8**	**7.1**	**0.0**	**0.0**	**8.9**
DUN	0.4	3.6	0.0	0.0	4.0
ELW	1.4	3.5	0.0	0.0	4.9
South Central Cascades	**614.7**	**414.0**	**13.0**	**332.3**	**1374.0**
South Sound	**614.7**	**414.0**	**13.0**	**332.3**	**1374.0**
DUW	286.5	23.4	0.0	4.0	313.9
PUY	93.4	282.4	0.0	42.7	418.5
NSQ	56.7	60.4	13.0	285.6.	415.7
DES	178.1	47.7	0.0	0.0	225.8
Total	**1988.1**	**721.1**	**592.5**	**472.1**	**3773.8**

Table A-2. Perimeter of channel features by delta and MPG in time period 1 (2010-2012). Steelhead MPGs = North Cascades, Olympic, and South Central Cascades; Chinook MPGs = Georgia Strait, North Sound, Hood Canal, Juan de Fuca, and South Sound. Delta name abbreviations are listed in the caption for Table A-1.

Steelhead MPG, Chinook MPG, Delta	Distributary Perimeter (km)	Tidal Channel Perimeter (km)	Tidal Complex Perimeter (km)	Tidal Flat Perimeter (km)	Total Perimeter (km)
Northern Cascades	**382.5**	**1523.3**	**371.3**	**140.2**	**2417.3**
Georgia Strait	**54.7**	**49.5**	**5.8**	**14.2**	**124.3**
NKS	54.7	49.5	5.8	14.2	124.3
North Sound	**327.7**	**1473.8**	**365.5**	**126.0**	**2293.0**
SAM	15.4	17.5	0.7	0.5	34.1
SWI	9.7	60.2	8.0	4.9	82.8
SKG	133.2	760.9	205.3	19.9	1119.3
STL	40.4	150.5	104.3	0.0	295.2
SNH	129.1	484.8	47.2	100.7	761.8
Olympic	**26.5**	**284.0**	**48.9**	**38.5**	**397.9**
Hood Canal	**25.6**	**266.2**	**48.9**	**38.5**	**379.2**
QUL	3.0	43.4	19.9	2.6	68.9
DOS	1.0	18.2	1.2	0.6	21.0
DUC	2.0	13.1	3.3	0.2	18.6
HAM	3.3	16.0	9.3	0.0	28.6
SKO	12.0	132.7	15.2	35.1	195.0
UNI	4.3	42.8	0.0	0.0	47.1
Juan de Fuca	**0.9**	**17.8**	**0.0**	**0.0**	**18.7**
DUN	0.4	12.0	0.0	0.0	12.4
ELW	0.5	5.8	0.0	0.0	6.3
South Central Cascades	**110.6**	**537.4**	**40.0**	**426.4**	**1114.4**
South Sound	**110.6**	**537.4**	**40.0**	**426.4**	**1114.4**
DUW	47.3	17.4	0.0	0.0	71.0
PUY	23.4	66.1	0.0	31.8	121.3
NSQ	26.0	443.7	40.0	388.2	897.9
DES	13.9	10.4	0.0	0.0	24.3
Total	**519.6**	**2344.7**	**460.1**	**605.1**	**3929.5**

Table A-3. Area (hectares) of channel features by delta and MPG in time period 2 (2017-2021). Steelhead MPGs = North Cascades, Olympic, and South Central Cascades; Chinook MPGs = Georgia Strait, North Sound, Hood Canal, Juan de Fuca, and South Sound. Delta name abbreviations are listed in the caption for Table A-1.

Steelhead MPG, Chinook MPG, Delta	**Distributary Area (ha)**	**Tidal Channel Area (ha)**	**Tidal Complex Area (ha)**	**Tidal Flat Area (ha)**	**Total Area (ha)**
Northern Cascades	**1342.5**	**322.1**	**727.4**	**233.8**	**2625.8**
Georgia Strait	**89.4**	**12.0**	**1.7**	**1.8**	**104.9**
NKS	89.4	12.0	1.7	1.8	104.9
North Sound	**1253.0**	**310.2**	**725.7**	**232.0**	**2520.9**
SAM	18.9	8.6	0.3	0.2	28.0
SWI	71.8	27.0	2.2	1.1	102.1
SKG	502.1	152.4	425.9	48.1	1128.5
STL	103.4	38.7	255.0	4.8	401.9
SNH	130.4	693.6	51.3	263.6	1138.9
Olympic	**46.8**	**47.9**	**17.4**	**9.7**	**121.8**
Hood Canal	**44.4**	**40.0**	**17.4**	**9.7**	**111.5**
QUL	2.0	52.4	17.2	2.7	74.2
DOS	4.1	19.5	0.9	0.3	24.8
DUC	3.6	12.1	0.9	0.0	16.6
HAM	3.2	16.5	3.8	0.0	23.5
SKO	13.2	141.8	9.0	27.8	191.8
UNI	4.3	64.7	0.0	1.0	70.0
Juan de Fuca	**2.3**	**7.9**	**0.0**	**0.0**	**10.2**
DUN	0.4	13.0	0.0	0.0	13.4
ELW	0.9	12.7	0.0	0.0	13.6
South Central Cascades	**619.1**	**421.6**	**10.4**	**297.5**	**1348.6**
South Sound	**619.1**	**421.6**	**10.4**	**297.5**	**1348.6**
DUW	48.3	17.7	0.0	6.6	72.6
PUY	23.6	72.1	0.0	31.4	127.1
NSQ	25.9	505.2	39.2	426.6	996.9
DES	14.0	10.7	0.0	0.0	24.7
Total	**2008.3**	**791.7**	**755.2**	**541.0**	**4096.2**

Table A-4. Perimeter of channel features by delta and MPG in time period 2 (2017-2021). Steelhead MPGs = North Cascades, Olympic, and South Central Cascades; Chinook MPGs = Georgia Strait, North Sound, Hood Canal, Juan de Fuca, and South Sound. Delta name abbreviations are listed in the caption for Table A-1.

Steelhead MPG, Chinook MPG, Delta	Distributary Perimeter (km)	Tidal Channel Perimeter (km)	Tidal Complex Perimeter (km)	Tidal Flat Perimeter (km)	Total Perimeter (km)
Northern Cascades	**414.4**	**2187.0**	**541.4**	**327.4**	**3470.2**
Georgia Strait	**57.4**	**105.1**	**1.6**	**2.3**	**166.4**
NKS	57.4	105.1	1.6	2.3	166.4
North Sound	**357.0**	**2081.9**	**539.8**	**325.1**	**3303.8**
SAM	15.7	20.8	0.7	0.6	37.8
SWI	9.7	67.0	8.0	3.8	88.5
SKG	152.7	1020.4	313.5	48.9	1535.5
STL	48.6	280.0	166.3	8.2	503.1
SNH		393.1	84.6	101.2	795.3
Olympic	**31.7**	**332.8**	**31.8**	**31.7**	**428.0**
Hood Canal	**30.5**	**307.1**	**31.8**	**31.7**	**401.1**
QUL	4.3	36.3	24.5	3.5	72.0
DOS	0.9	24.3	3.0	0.3	30.7
DUC	0.9	15.9	4.8	1.1	27.2
HAM	3.0	15.3	6.3	8.3	37.0
SKO	6.1	122.9	59.9	40.3	237.9
UNI					
Juan de Fuca	**1.2**	**25.7**	**0.0**	**0.0**	**26.9**
DUN	0.9	17.0	0.0	3.5	25.3
ELW	0.0	6.0	0.0	1.6	9.2
South Central Cascades	**111.8**	**605.6**	**39.2**	**464.6**	**1221.2**
South Sound	**111.8**	**605.6**	**39.2**	**464.6**	**1221.2**
DUW	8.0	4.8	0.0	4.0	47.5
PUY	17.6	7.5	0.0	13.9	84.7
NSQ	21.9	247.8	51.0	98.1	427.6
DES	0.0	2.5	1.9	22.1	48.1
Total	**557.9**	**3125.4**	**612.5**	**823.8**	**5119.6**

Table A-5. Count of Overwater Structures by Marine Basin and Land Cover Class (LCC) for 2013-2016 survey period. Marine Basins = Hood Canal, North Puget Sound, South Central Puget Sound, Strait of Juan de Fuca, and Whidbey Basin. Land Cover Class = Agriculture (Ag), Developed (D), Forest (F), and Mixed (M). Land cover classes are collated from NOAA C-CAP data; the mixed class is assigned to areas with no dominant land cover class over 50%.

Marine Basin	LCC	Structure Type						
		Aquaculture	Boat Rail	Bridge	Buoy/Float	Dock/Pier	Log Boom	Total Count
Hood Canal Total		**112**	**162**	**126**	**284**	**1076**		**1760**
Hood Canal	Ag				1	3		4
	D	6	15	20	20	257		318
	F	103	145	104	258	792		1402
	M	3	2	2	5	24		36
North Puget Sound Total		**8**	**32**	**71**	**130**	**1199**		**1440**
North Puget Sound	Ag			6	6	33		45
	D	1	6	29	24	427		487
	F	5	25	34	95	690		849
	M	2	1	2	5	49		59
South Central Puget Sound Total		**122**	**179**	**241**	**1094**	**3520**	**27**	**5183**
South Central Puget Sound	Ag	3			2	5		10
	D	17	57	92	231	1291	6	1694
	F	102	121	148	855	2201	21	3448
	M		1	1	6	23		31
Strait of Juan de Fuca Total		**7**	**5**	**35**	**16**	**185**	**6**	**254**
Strait of Juan de Fuca	Ag			3	1	2		6
	D	1		15	2	89	6	113
	F	6	2	15	11	80		114
	M		3	2	2	14		21
Whidbey Basin Total		**42**	**52**	**55**	**99**	**596**	**28**	**872**
Whidbey Basin	Ag	4	1	6	4	6		21
	D		27	22	30	359	9	447
	F	38	18	23	65	225	19	388
	M		6	4		6		16
Total Count		**291**	**430**	**528**	**1623**	**6576**	**61**	**9509**

Table A-6. Count of Overwater Structures by Marine Basin and Land Cover Class (LCC) for 2021 survey period. Marine Basins = Hood Canal, North Puget Sound, South Central Puget Sound, Strait of Juan de Fuca, and Whidbey Basin. Land Cover Class = Agriculture (Ag), Developed (D), Forest (F), and Mixed (M). Land cover classes are collated from NOAA C-CAP data and a Mixed class is assigned to areas with no dominant land cover class over 50%.

Marine Basin	LCC	Structure Type						
		Aquaculture	Boat Rail	Bridge	Buoy/Float	Dock/Pier	Log Boom	Total Count
Hood Canal Total		**88**	**159**	**125**	**510**	**1052**		**1934**
Hood Canal	Ag				2	3		5
	D	4	15	18	37	253		327
	F	79	142	105	463	771		1560
	M	5	2	2	8	25		42
North Puget Sound Total		**7**	**23**	**67**	**119**	**1183**		**1399**
North Puget Sound	Ag			6	8	31		45
	D		3	29	21	415		468
	F	2	19	31	83	685		820
	M	5	1	1	7	52		66
South Central Puget Sound Total		**65**	**149**	**238**	**1239**	**3442**	**20**	**5153**
South Central Puget Sound	Ag	1			1	5		7
	D	9	48	91	242	1253	4	1647
	F	55	100	146	992	2164	16	3473
	M		1	1	4	20		26
Strait of Juan de Fuca Total		**2**	**5**	**32**	**12**	**182**		**233**
Strait of Juan de Fuca	Ag			3		2		5
	D			13		83		96
	F	2	2	14	9	81		108
	M		3	2	3	16		24
Whidbey Basin Total		**42**	**46**	**56**	**47**	**552**	**4**	**747**
Whidbey Basin	Ag	4	1	7	4	5		21
	D		23	22	17	348	1	411
	F	38	16	23	26	193	3	299
	M		6	4		6		16
Total Count		**204**	**382**	**518**	**1927**	**6411**	**24**	**9466**

Table A-7. Area of Overwater Structures by Marine Basin and Land Cover Class (LCC) in M^2 for 2013-2016 survey period. Marine Basins = Hood Canal, North Puget Sound, South Central Puget Sound, Strait of Juan de Fuca, and Whidbey Basin. Land Cover Class = Agriculture (Ag), Developed (D), Forest (F), and Mixed (M). Land cover classes are collated from NOAA C-CAP data; the mixed class is assigned to areas with no dominant land cover class over 50%.

Marine Basin	**LCC**	**Structure Type**						
		Aquaculture	**Boat Rail**	**Bridge**	**Buoy/Float**	**Dock/Pier**	**Log Boom**	**Grand Total**
Hood Canal Total		**374,834.04**	**6,261.27**	**80,611.81**	**12,966.71**	**475,500.93**		**950,174.76**
Hood Canal	Ag				18.58	257.38		275.96
	D	1,009.88	806.55	2,665.26	334.19	108,405.84		113,221.72
	F	373,790.59	5,387.02	77,892.63	12,514.25	350,107.69		819,692.18
	M	33.57	67.71	53.92	99.69	16,730.02		16,984.91
North Puget Sound Total		**34,085.68**	**2,264.14**	**32,631.84**	**13,394.64**	**1,060,306.94**		**1,142,683.23**
North Puget Sound	Ag			3,513.70	141.97	23,668.92		27,324.59
	D	984.22	995.33	23,193.53	4,128.13	757,472.70		786,773.90
	F	29,708.62	1,218.73	5,853.15	8,955.45	237,089.17		282,825.12
	M	3,392.84	50.08	71.47	169.10	42,076.15		45,759.63
South Central Puget Sound Total		**149,306.71**	**9,192.11**	**337,019.01**	**72,732.82**	**2,772,544.19**	**117,462.41**	**3,458,257.24**
South Central Puget Sound	Ag	520.56			34.29	2,784.22		3,339.07
	D	55,123.62	3,203.81	199,577.90	35,221.92	2,213,183.01	21,785.46	2,528,095.71
	F	93,662.53	5,936.46	137,346.02	37,390.06	555,003.17	95,676.95	925,015.19
	M		51.84	95.09	86.55	1,573.79		1,807.26
Strait of Juan de Fuca Total		**17,177.68**	**127.97**	**9,315.77**	**3,384.80**	**197,932.14**	**44,633.97**	**272,572.33**
Strait of Juan de Fuca	Ag			998.89	56.35	468.82		1,524.06
	D	5,243.59		2,471.48	1,688.70	177,138.86	44,633.97	231,176.60
	F	11,934.09	85.07	5,752.77	1,606.83	19,151.98		38,530.73
	M		42.91	92.62	32.93	1,172.47		1,340.93
Whidbey Basin Total		**26,186.11**	**2,605.30**	**107,475.62**	**12,920.89**	**484,167.00**	**138,329.59**	**771,684.52**
Whidbey Basin	Ag	1,322.42	23.09	6,793.11	61.37	545.00		8,744.98
	D		1,335.32	83,309.98	4,540.95	432,012.61	53,440.87	574,639.73
	F	24,863.70	720.47	12,429.94	8,318.57	50,780.94	84,888.73	182,002.35
	M		526.43	4,942.59		828.45		6,297.47
Total Count		**601,590.22**	**20,450.79**	**567,054.05**	**115,399.86**	**4,990,451.20**	**300,425.97**	**6,595,372.09**

Table A-8. Area of Overwater Structures by Marine Basin and Land Cover Class (LCC) in M^2 for 2021 survey period. Marine Basins = Hood Canal, North Puget Sound, South Central Puget Sound, Strait of Juan de Fuca, and Whidbey Basin. Land Cover Class = Agriculture (Ag), Developed (D), Forest (F), and Mixed (M). Land cover classes are collated from NOAA C-CAP data; the mixed class is assigned to areas with no dominant land cover class over 50%.

Marine Basin	LCC	Structure						
		Aquaculture	Boat Rail	Bridge	Buoy/Float	Dock/Pier	Log Boom	Grand Total
Hood Canal Total		**379,931.72**	**6,211.83**	**80,710.58**	**14,087.95**	**481,498.11**		**962,440.19**
Hood Canal	Ag				28.76	257.38		286.14
	D	201.84	806.55	2,658.15	510.91	108,891.80		113,069.25
	F	379,019.75	5,337.57	77,998.51	12,739.89	355,723.08		830,818.79
	M	710.13	67.71	53.92	808.39	16,625.86		18,266.01
North Puget Sound Total		**12,144.70**	**977.95**	**30,590.02**	**12,274.61**	**1,077,519.87**		**1,133,507.15**
North Puget Sound	Ag			3,157.89	271.82	23,598.73		27,028.44
	D		174.76	21,621.21	3,778.29	771,419.07		796,993.33
	F	5,024.61	753.12	5,755.53	7,958.44	238,953.44		258,445.14
	M	7,120.09	50.08	55.39	266.06	43,548.63		51,040.24
South Central Puget Sound Total		**119,574.85**	**7,524.17**	**331,520.99**	**47,101.80**	**2,824,569.89**	**90,466.94**	**3,420,758.64**
South Central Puget Sound	Ag	35.21			12.52	2,784.22		2,831.95
	D	20,416.06	2,843.79	194,564.79	17,448.36	2,287,861.36	15,910.82	2,539,045.17
	F	99,123.58	4,628.55	136,861.11	29,586.65	532,339.58	74,556.12	877,095.60
	M		51.84	95.09	54.26	1,584.72		1,785.91
Strait of Juan de Fuca Total		**17,400.56**	**127.97**	**10,062.32**	**1,610.30**	**206,549.23**		**235,750.38**
Strait of Juan de Fuca	Ag			1,923.65		468.82		2,392.47
	D			2,348.46		185,361.84		187,710.30
	F	17,400.56	85.07	5,697.59	1,565.12	19,477.92		44,226.26
	M		42.91	92.62	45.18	1,240.64		1,421.35
Whidbey Basin Total		**26,339.69**	**2,417.19**	**107,521.26**	**5,271.97**	**456,289.07**	**26,792.52**	**624,631.69**
Whidbey Basin	Ag	1,322.42	23.09	6,838.75	61.37	510.20		8,755.83
	D		1,202.20	83,309.98	3,060.01	416,687.46	9,667.54	513,927.19
	F	25,017.27	665.48	12,429.94	2,150.58	38,262.96	17,124.98	95,651.21
	M		526.43	4,942.59		828.45		6,297.47
Grand Total		**555,391.51**	**17,259.12**	**560,405.17**	**80,346.62**	**5,046,426.17**	**117,259.45**	**6,377,088.05**

U.S. Secretary of Commerce
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