

Final

LAND COVER DEMONSTRATION PROJECT

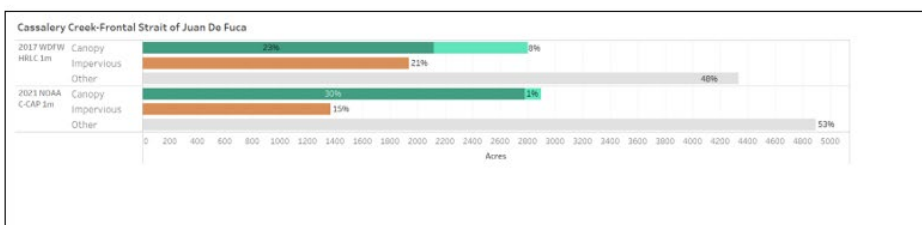
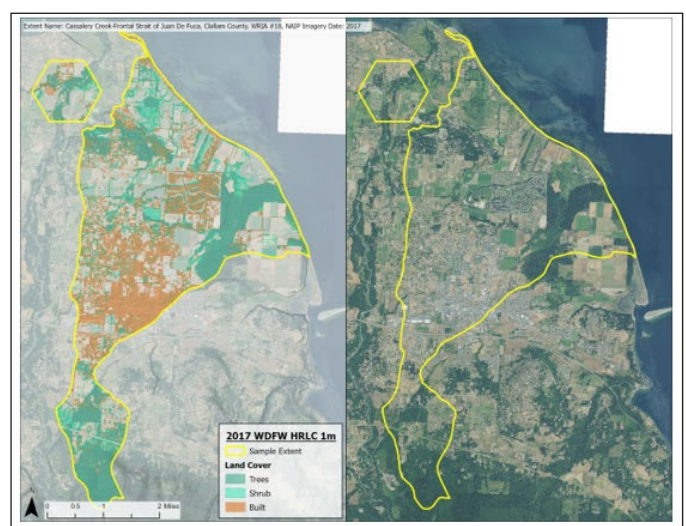
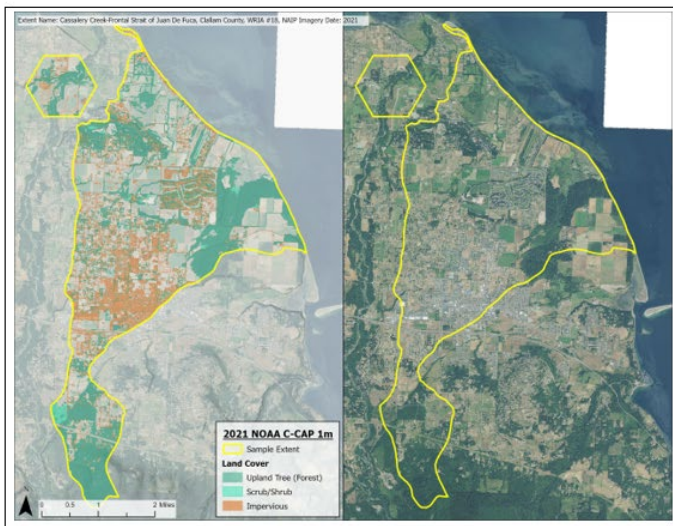
Geospatial Services

Prepared for
Puget Sound Partnership

June 2024



Clallam County – Cassalery Creek-Frontal Strait of Juan De Fuca



General Observations: This location shows 30% of the extent mapped as Upland Tree (Forest) and 1% Scrub/Shrub for 2021 NOAA C-CAP 1m vs 23% of the extent mapped as Trees and 8% as Shrub for the 2017 WDFW HRLC. Similarly, 15% of the extent is mapped as Impervious for NOAA C-CAP while 21% of the extent is mapped as Built for WDFW HRLC.

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TABLE OF CONTENTS

Land Cover Demonstration Project

	<u>Page</u>
Acronyms and Other Abbreviations.....	iii
Section 1	1-1
Introduction	1-1
Uses of Land Cover for Puget Sound Recovery	1-1
Organization of This Report	1-2
Section 2	2-3
High-Resolution Land Cover.....	2-3
What is High-Resolution Data?	2-3
High-Resolution Products Compared to Traditional Products	2-3
Section 3	3-1
Land Cover Datasets	3-1
Introduction	3-1
WDFW High Resolution Land Cover.....	3-1
NOAA C-CAP 30-Meter Resolution Land Cover	3-6
NOAA High-Resolution Land Cover Data	3-9
Section 4	4-1
Assessment.....	4-1
Results and Findings	4-3
Section 5	5-1
Other Land Cover Datasets and Related Products	5-1
Introduction	5-1
Ecology Statewide Wetland Mapping Inventory	5-1
National Land Cover Database	5-1
Esri/Microsoft Sentinel-2 10m Land Cover	5-2
Microsoft US Building Footprints	5-2
Open Street Map	5-2
Others	5-3
Section 6	6-1
Guidance and Recommendations	6-1
Guidance for Practitioners.....	6-1
Gaps	6-2
Recommendations for Investment in Programs	6-2
Section 7	7-1
References.....	7-1

Figures

Figure 2-1	Comparison of 30m and 1m Spatial Resolution NOAA C-CAP Land Cover Data Products	2-3
Figure 3-1	WDFW High Resolution Land Cover Classes	3-1
Figure 3-2	WDFW Land Cover Availability by County	3-2
Figure 3-3	WDFW Modeled Vegetation Heights Example	3-3
Figure 3-4	Example of NOAA's 30-m Resolution Land Cover Data Product near Vancouver, Washington	3-6
Figure 3-5	Example of NOAA's High Resolution Land Cover Data Products for Impervious, Canopy and Water Cover Types	3-9
Figure 4-1	Puget Sound Assessment Locations	4-2
Figure 4-2	Assessment Location Detailed Results	4-5
Figure 4-3	WDFW High-Resolution Change Detection for Lake Aldwell-Elwha River in Clallam County	4-6
Figure 4-4	Example of NOAA C-CAP 2011-2016 Change Detection for the Snohomish River-Frontal Possession Sound Watershed in Snohomish County	4-8
Figure 4-5	Example of NOAA C-CAP 2021 HRLC for the Stillaguamish River-Frontal Port Susan Watershed in Snohomish County	4-9
Figure 4-6	Example of 2021 WDFW 1m Land Cover for Thurston County	4-9

Tables

Table 3-1	County Land Cover Data Availability by Year	3-2
Table 4-1	Datasets Evaluated as Part of Assessment	4-1
Table 4-2	Datasets Strengths and Weaknesses Summary	4-4
Table 4-3	WDFW High-Resolution Change Detection Summary Statistics for Assessment Locations	4-7
Table 4-4	Summary of other land cover data products and related datasets	5-3

Appendices

A. Detailed Results

Acronyms and Other Abbreviations

Acronym or Abbreviation	Definition
C-CAP	Coastal Change Analysis Program
CDL	Cropland Data Layer
EPA	Environmental Protection Agency
ESA	Environmental Science Associates
Esri	Environmental Systems Research Institute
GAP	Gap Analysis Project
HRCD	High-Resolution Change Detection
HRLC	High-Resolution Land Cover
LiDAR	Light Detection and Ranging
NAIP	National Agriculture Imagery Program
NDVI	Normalized Difference Vegetation Index
NLCD	National Land Cover Dataset
NOAA	National Oceanic and Atmospheric Administration
NWI	National Wetlands Inventory
OSM	Open Street Map
PSEMP	Puget Sound Ecosystem Monitoring Program
PSP	Puget Sound Partnership
SDWG	Spatial Data Work Group
USDA	United States Department of Agriculture
USGS	United States Geological Survey
WDFW	Washington Department of Fish and Wildlife
WDNR	Washington Department of Natural Resources

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SECTION 1

Introduction

The purpose of this Land Cover Demonstration Project is to evaluate and provide recommendations for the application of high-resolution land cover (HRLC) data from a variety of state and national land cover programs to inform local geographic prioritization and to track regional progress of the protection and restoration of habitats for recovering Puget Sound Salmon. The evaluation includes documenting analysis workflows to assess a range of questions related to the issues above. Audiences for this report include, but are not limited to, habitat restoration practitioners, geospatial practitioners, natural resource managers, the Environmental Protection Agency (EPA), the Puget Sound Partnership (PSP), and the Puget Sound Ecosystem Monitoring Program (PSEMP) Spatial Data Work Group (SDWG).

The Demonstration Project was funded by a grant from EPA to PSP. The project was coordinated through the SDWG. This report summarizes the results of the Demonstration Project, which focuses on land cover data developed by the Washington Department of Fish and Wildlife (WDFW) and the National Oceanic and Atmospheric Administration (NOAA). The report details the following:

- The process and evaluation of the land cover datasets, including identification of the strengths, caveats, and trade-offs of the datasets.
- Potential applications for the datasets, including guidance regarding application of datasets and associated analyses or workflows.
- Recommendations for funding and support to the respective land cover programs for the NOAA Coastal Change Analysis Program (C-CAP) and WDFW in the future.

Uses of Land Cover for Puget Sound Recovery

Land cover data is a useful tool for Puget Sound recovery that is currently underutilized throughout the region. Land cover data can be used to:

- Assess and characterize conditions,
- Inform efforts to plan restoration projects, protection measures, and policies,
- Track and measure progress,
- Contextualize monitoring results and other environmental data, and,
- Inform adaptive management strategies.

Specific examples of the use of land cover for Puget Sound recovery include:

- **Land Cover and Development Implementation Strategy.** One of eight completed Implementation Strategies for Puget Sound, the Land Cover and Development Implementation Strategy was co-led by WDFW and the Washington Department of Natural Resources (WDNR). The Implementation Strategy identifies a goal (“to reduce conversion of ecologically important lands from forests, agricultural lands, and natural areas into homes, businesses, and roads”) and a set of strategies to achieve that goal. The Implementation Strategy also identifies an indicator to be tracked and reported on using land cover data. For more information, visit the site at: <https://pugetsoundestuary.wa.gov/land-development-and-cover/>.
- **Puget Sound Vital Signs Indicators.** The Vital Signs indicators are measures of ecosystem health and progress toward Puget Sound recovery goals. PSP coordinates reporting on the Vital Signs indicators and several Vital Signs indicators rely on land cover data to track ecosystem health. For more information, visit the site at: <https://vitalsigns.pugetsoundinfo.wa.gov/>.
- Washington Department of Ecology’s **Puget Sound Watershed Characterization Project.** The Watershed Characterization project is a regional-scale initiative that aims to identify critical areas for protection, restoration, and development within the Puget Sound. The characterization includes assessments for water flow, water quality and fish & wildlife habitat along with a newer hydrologic conditions index helping to assess stream flashiness. The characterization includes a companion tool that uses land cover data to support several of these assessments for characterizing conditions at a sub-watershed/drainage scale. For more information, visit the site at: <https://ecology.wa.gov/water-shorelines/puget-sound/watershed-characterization-project>.

Organization of This Report

The report includes the following sections:

- Section 1 – Introduction
- Section 2 – High Resolution Land Cover
- Section 3 – Land Cover Datasets
- Section 4 – Assessment (including Methodology, Results, and Findings)
- Section 5 – Other Land Cover Datasets and Related Products
- Section 6 – Guidance and Recommendations

SECTION 2

High-Resolution Land Cover

What is High-Resolution Data?

High-resolution spatial data is captured and represented with a higher level of detail and precision, which supports the accurate depiction of smaller geographies than lower resolution data. The resolution of spatial data refers to the size of individual pixels in an image or rasterized spatial data, with high-resolution spatial data having more pixels in a given area of land cover than lower resolution data (see **Figure 2-1**).

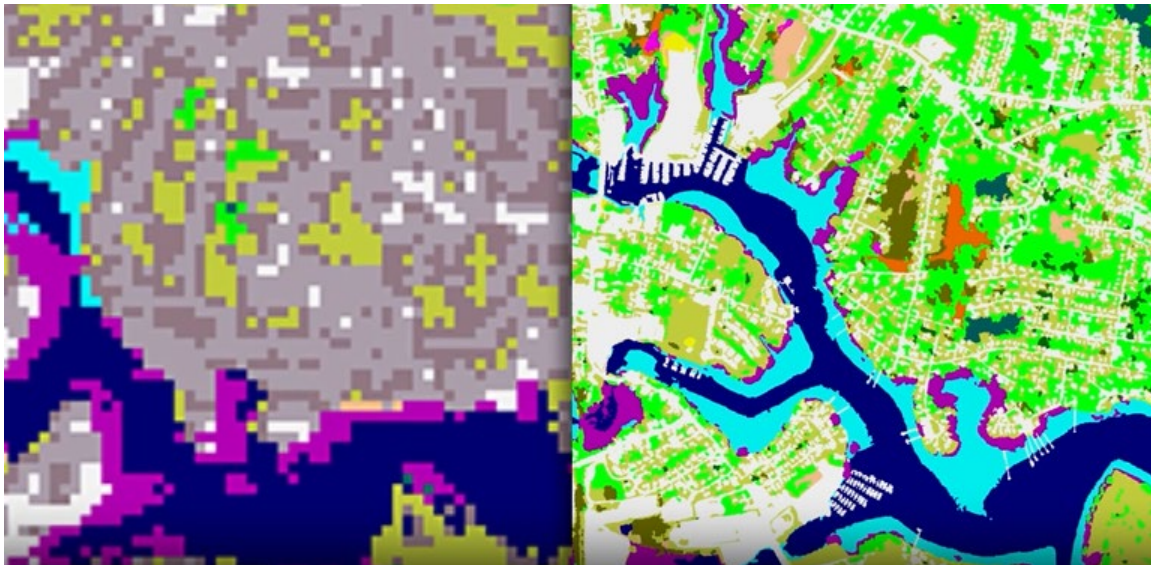


Figure 2-1 Comparison of 30m and 1m Spatial Resolution NOAA C-CAP Land Cover Data Products

Pixels in high-resolution spatial data typically depict an area of five square meters or smaller, with NOAA and WDFW high-resolution datasets having approximately one pixel per one square meter.

High-Resolution Products Compared to Traditional Products

High-resolution spatial data captures more details and, in many cases, with greater accuracy than lower-resolution data. This can support a greater number of land management use cases and the

potential for more accurate analysis of environmental conditions. The disadvantages of high-resolution data are the higher cost and larger file size compared to traditional products.

The ability to capture and represent smaller features accurately allows for the visualization of more detailed information. Traditional 30-meter resolution data products depict one pixel for every 30 by 30-meter area. In contrast, 1-meter high-resolution data products depict 900 pixels for the same area, with each pixel representing one square meter of spatial data. High-resolution imagery used to develop these data products can be assessed using modern methods that combine object-based approaches with machine learning and deep learning models for classification. Rather than solely relying on pixel-level analysis, these advanced techniques convert pixels to polygons, providing a more holistic view of land cover features. This allows for a more accurate representation of land cover features that may be split across multiple cells in the image grid, as the object-based approach groups these pixels into meaningful objects. Consequently, smaller features that would need to be the size of multiple pixels to be reliably captured in traditional pixel-based land cover data can now be effectively identified and classified using these sophisticated methods. Many land cover models now work on multi-pixel objects, achieved through segmentation processes or generated using deep learning methods that summarize spatial patterns to generate pixel-level predictions during semantic segmentation. This approach allows for the capture of smaller features, such as single-family homes on large lots or small groups of trees in urban environments, which were previously unable to be mapped in traditional coarse-scale land cover data products.

While these high-resolution data products are still not recommended as the sole source for site-specific decision-making, it is much more likely to contain relevant information for local-scale planning, monitoring and prioritization efforts. The potential for identifying individual trees, particularly single independent trees above a certain size threshold, could provide substantial insight for geographic analysis of natural resources, such as restoration monitoring and wetland mapping. However, it is important to note that while 1-meter data offers finer detail, it is also much easier to challenge or falsify compared to 30-meter data. This finer granularity might expose the limitations of data accuracy, especially for overlapping classes such as coniferous forest versus coniferous wetland forest, or range versus agriculture, which could challenge previous assumptions about the reliability and the extent of information conveyed by these models. High-resolution land cover data also has increased potential for localized analysis of built environments, such as identifying land cover changes at building scales, which can inform stormwater management and flood risk assessment modeling. More coarse-scale data products could serve similar mapping and analytical functions, but at lower resolutions and with less confidence. High-resolution geospatial data is valuable for site-specific uses, offering finer detail that enhances geographic analysis of natural resources and built environments, though it can also reveal limitations in data accuracy and reliability for some overlapping classes.

As a relatively new development in publicly available geospatial data, high-resolution products have drawbacks that can provide challenges for end users. The greater amount of detail in high-resolution data products results in a larger volume of data than traditional products when mapping the same geographic area. This creates a greater demand for data management and storage requirements for both the entity creating and hosting the data, as well as for individual users. The

size of the data files and increased level of detail may require more resources for processing and analyzing data, including staff, time, or computer resources dedicated towards activities required for generating or managing data. Due to the various additional resource requirements for high-resolution data, the cost of acquiring, generating, publishing or hosting and managing the data is greater than traditional data products.

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SECTION 3

Land Cover Datasets

Introduction

NOAA and WDFW both produce land cover spatial data for use in the Southern Salish Sea / Puget Sound NEP area. The most recent iterations of both of these datasets are high resolution, with land cover classifications at scales as small as one meter. Developing HRLC data can present costs and challenges that are unique compared to lower resolution datasets, but the higher resolutions also provide opportunities for more detailed depictions of land cover and more localized uses of the data.

WDFW High Resolution Land Cover

The WDFW HRLC dataset is developed through analysis of multiple data products, which are used to classify land cover and identify change in land cover over time (see **Figure 3-1**). The WDFW HRLC data products have been published for select counties in 2011, 2017 (which included canopy height data), and 2019. Additionally, the WDFW High-Resolution Change Detection (HRCDD) data product depicts land cover changes over time in select counties.

Dataset Background and Purpose

Land cover data is available for select counties in 2011, 2017, and 2019 (see **Table 3-1**). Some areas within these counties have been analyzed for land cover change detection for years that land cover data has not been published, including changes as recent as 2021 and as old as 2006. WDFW is currently developing 2021 data.



Figure 3-1

WDFW High Resolution Land Cover Classes

**TABLE 3-1
COUNTY LAND COVER DATA AVAILABILITY BY YEAR**

Year	Counties with Data
2011	Clark, Columbia, Grays Harbor, Kittitas, Lewis, Pacific, Pend Oreille, Thurston
2017	Clallam, Clark, Columbia, Grays Harbor, Island, Jefferson, King, Kitsap, Kittitas, Lewis, Mason, Pacific, Pend Oreille, Pierce, San Juan, Skagit, Skamania, Snohomish, Wahkiakum, Whatcom
2019	Skagit

NOTE:

1. Check the WDFW High Resolution Land Cover page for the latest updates on data availability including the availability of 2021 data products: <https://hrcd-wdfw.hub.arcgis.com/pages/land-cover>.

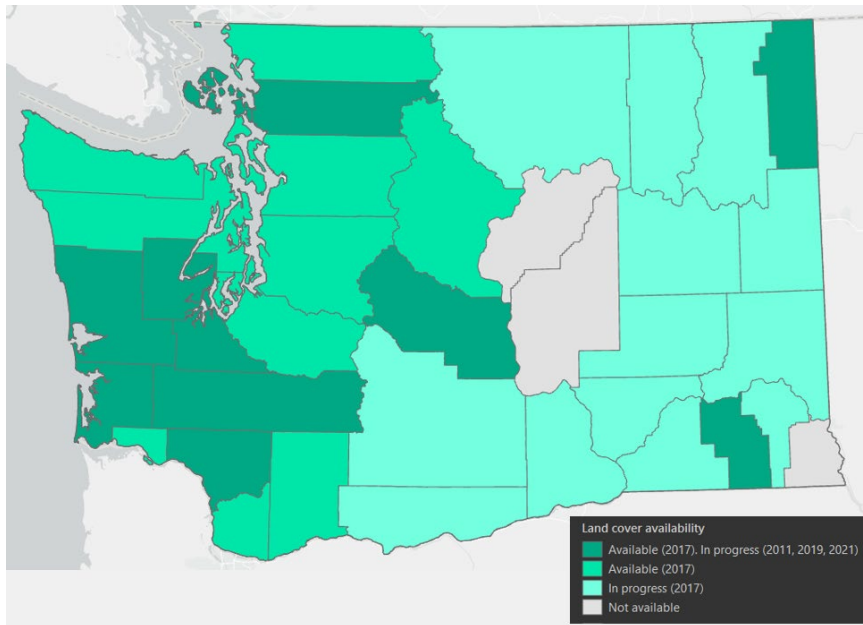


Figure 3-2 WDFW Land Cover Availability by County

The dataset delineates land cover into seven classifications:

- Built (areas dominated by human-built structures and impervious surface)
- Gravel (areas of primarily gravel or sand along rivers and streams)
- Ground (bare ground, such as non-water related gravel, rock, or dirt)
- Herbaceous (vegetation less than 5 feet tall)
- Shrub (vegetation 5-15 feet tall)
- Trees (vegetation over 15 feet tall)
- Water (areas of open water)

Strengths

Key strengths for WDFW’s land cover data include the high level of resolution and the detail in the vegetation data. WDFW has modeled for vegetation height, which can support the identification of different habitat types, as well as distinct classifications in vegetated ground cover: trees, shrubs, and herbaceous, with tree cover mapping being the most accurate vegetation classifications. Each polygon-based feature also has attributes for Normalized Difference Vegetation Index (NDVI), along with average, minimum, maximum, and standard deviation values. Another strength is the data’s ability to map rough edges and natural features on the landscape.

While high resolution data can be effective for identification of individual buildings and other structures in the built environment, the precision of land cover detection in the built environment remains a weakness, especially around straight lines, such as building perimeters. Identification of bare ground and herbaceous vegetation can also have a heightened likelihood of classification errors, due to similarities in appearance to other land cover classes. WDFW also notes limitations with the shrub cover type and is included to cover the uncertain area between herbaceous and trees and is a common limitation for all land cover products that include this category.



Figure 3-3 WDFW Modeled Vegetation Heights Example

Allowable Uses and Restrictions

The only official restriction on the WDFW HRLC dataset is that WDFW must be cited as the source for the data. However, it is strongly advised that HRLC data not be used for site-scale

decisions. The data is also not intended to be used for distinguishing species or types of vegetation, such as identifying coniferous versus deciduous trees.

Intended uses of the datasets include:

- Assessing the land cover of habitats, especially riparian habitats,
- Identifying tree canopy height,
- Estimating tree canopy coverage, and
- Informing environmental plans, such as forest stewardship plans.

Examples of Use

As noted above, there are several common uses of the WDFW dataset. Below are some specific example projects that utilized WDFW's HRLC data. The HRLC dataset is distinct but complementary to another WDFW data product, HRCD, which is detailed later in this section. This data can be used to assess causes of land cover change, rate of change, ecosystem health, and habitat fragmentation or reconnection, among other potential uses.

Floodplains for the Future Monitoring Program

The Floodplains for the Future Monitoring Program tracks landscape metrics in Washington's Puyallup River Watershed, which provide insights into floodplain health, salmon recovery, and agriculture. One of the metrics the program tracks is the acreage of floodplain that is natural or connected to the river, which is partially informed by the acreage of restoration projects performed in floodplains. Utilizing HRCD data, the program was able to compare the acres of restoration over a specified time period with acres of new built environment (presented as increases in impervious and semi-pervious surface in the HRCD data). This analysis allows for demonstration that floodplain restoration is outpacing loss of connected/natural floodplain areas, resulting in net gains in this floodplain condition type (ESA 2021).

Voluntary Stewardship Program

The Washington State Conservation Commission oversees the Voluntary Stewardship Program, which involves the development of county-level plans to protect sensitive environments on agricultural land, while providing technical support to farmers through best management practices that balance agricultural viability and environmental stewardship. Eleven counties enrolled in the Voluntary Stewardship Program uses HRCD data to monitor outcomes of best management practices and develop required reports on progress towards stewardship goals. The HRCD data supports the identification of changes in sensitive environments, distinguishing between natural canopy losses, such as river movement, and anthropogenic changes, such as tree removal or development impacts (Washington State Conservation Commission 2023).

Capacity and Resources Needed

Resource needs can be difficult to determine due to the number of factors that can affect cost, including changes in the data used to produce the HRLC dataset. The cost for change detection and land cover data for the entire state of Washington for one time stamp was roughly estimated

at \$2 to 3 million for every four-year period. Producing a high-quality dataset also depends on the availability of LiDAR bare-earth data, DSM data (surface modelling by WDNR), and raw imagery, which are not included in that cost estimate. Additionally, the uncertain nature of funding for this work presents a significant challenge, similar to the issues faced by C-CAP. Another critical challenge is the latency of the mapping process; producing data faster, potentially with increased funding, would significantly benefit users by providing more timely and relevant information.

Related WDFW Data Products

WDFW performs further assessment of attributes of its land cover data to provide additional data products that provide higher levels of detail and can support more focused analysis of specific attributes.

Tree Canopy

WDFW's tree canopy data, as a subset of the HRLC dataset, provides additional useful information related to tree height and canopy extents. The tree canopy data delineates trees in polygons that may represent contiguous stands of many trees or discrete stands that may consist of only a few trees or a single tree. The data depicts any trees over 15-feet tall and provides information for each polygon including average height, minimum height, maximum height, and standard deviation of heights. The tree canopy data is useful and consistent across environments ranging from rural to urban. The data is available for most parts of western Washington and select areas in central and eastern Washington (WDFW 2022b).

High-Resolution Change Detection

WDFW's HRCD data is developed from comparisons between imagery from the National Agriculture Imagery Program (NAIP) from different time periods between 2006 and 2021. The data tracks three types of land cover change: tree canopy loss, impervious surface increases, and semi-pervious surface increases. This data consists of numerous other insightful attributes, including the primary cause of the change, whether the change was natural or human-caused, the total area of change, area of different types of change, and the time period over which the change occurred. Each area of change is manually reviewed by analysts to verify change and its cause, which improves the accuracy of the data. The data is available for the entire Puget Sound Region and select counties outside of the region (WDFW 2022a).

Visible Surface Water

WDFW's visible surface water data, developed using high-resolution imagery and specific to the 2017 time stamp, provides detailed depictions of surface water conditions, which can be more representative of current states compared to high-level hydrography spatial data. This is particularly useful for depicting rivers and streams prone to channel migration. The data categorizes visible surface water into six categories: pooled (such as lakes and wetlands), streams, gravel (in channel migration zones), shadow (where water is likely obscured), open water, and transition zones (such as shorelines). Surface water is identified through various approaches,

including local data, manual identification, automated software, and the National Hydrography Dataset.

WDFW data products are available for viewing and download on their High-Resolution Change Detection website at: <https://hrcd-wdfw.hub.arcgis.com/>.

NOAA C-CAP 30-Meter Resolution Land Cover

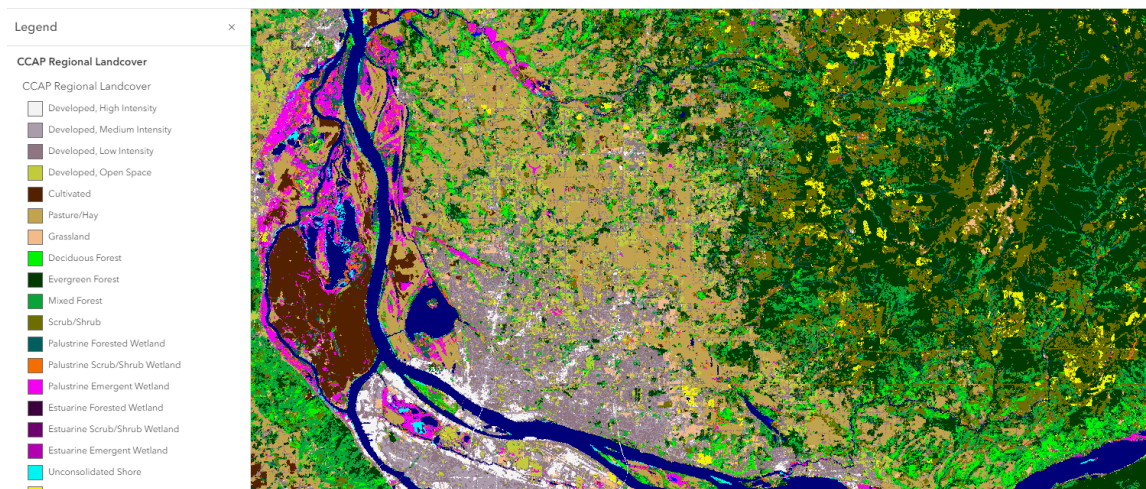


Figure 3-4 Example of NOAA's 30-m Resolution Land Cover Data Product near Vancouver, Washington

Dataset Background and Purpose

The C-CAP 30-meter resolution land cover datasets provide raster-based land cover classifications for coastal areas of the United States, including the Great Lakes Region. Remote sensing is used to detect different classes of land cover and comparisons are made between datasets from different years to detect land cover change. Most regions have at least 20 years of data. These datasets inform NOAA's Coastal Change Analysis Program and are used in national datasets, such as the National Land Cover Database and Land Cover Atlas.

Strengths

While NOAA does not have a mandate to produce or update the land cover datasets, they have been committed to doing such since the early 2000's. The Office for Coastal Management (OCM) team that is responsible for the dataset operates with a commitment to the coastal management community to maintaining consistency across the nation and through time. This commitment and consistency constitute a major strength of the data.

C-CAP data are recognized by the Federal Geographic Data Committee (FGDC) as a National Geospatial Data Asset (NGDA), and as such represents one of the authoritative sources for such data in the United States. Updates occur approximately every 5 years. Date ranges for most locations include 1996, 2001, 2006, 2011, 2016, with a 2021 update currently in progress. The data produced by NOAA seeks to map changes that have occurred on the ground, and while

changes in technology or methodology over the years have meant improvements to their mapping, they do not alter the resulting product (i.e. any improvements to methods are incorporated into the full time series, in order to ensure that difference from one date to the next are a result of only changes in condition, not methods or technology). The long time period of historical coverage, and the low cost of production are two additional strengths of the product line. These data can serve a vital role in historical analysis and provide a high-level overview of conditions and change, even if they are not able to support more local level analysis.

C-CAP land cover data includes 25 categories of land cover, including:

- Unclassified
- High Intensity Developed
- Medium Intensity Developed
- Low Intensity Developed
- Open Space Developed
- Cultivated
- Pasture/Hay
- Grassland
- Deciduous Forest
- Evergreen Forest
- Mixed Forest
- Shrub/Scrub
- Palustrine Forested Wetlands
- Palustrine Scrub/Shrub Wetlands
- Palustrine Emergent Wetlands
- Estuarine Forested Wetlands
- Estuarine Scrub/Shrub Wetlands
- Estuarine Emergent Wetlands Unconsolidated Shore
- Barren Land
- Open Water
- Palustrine Aquatic Bed
- Estuarine Aquatic Bed
- Perennial Snow/Ice

The large number of land cover classifications includes delineation of multiple categories of development, forests, wetlands, and farmland. The identification of impervious surfaces and wetlands are strengths in the NOAA data, which is held up under accuracy assessments. The strength of these classifications is notable as these are key factors in assessing ecosystem health and function. The strength of impervious and wetland classification, in addition to the availability of many other land cover classifications, allow for a wide variety of uses of this dataset. For its wide variety of uses, the 30-meter resolution land cover data is strong up to approximately a county scale, while more localized areas may have less accuracy or may not reflect small areas with different land cover than their surroundings.

Allowable Uses and Restrictions

NOAA develops its land cover datasets with the intent of making them applicable to a wide range of uses, which is supported by the lack of a specific mandate for developing the data. The 30-meter resolution dataset does not have any restrictions on its use or prescribed uses. However, using the data for regulatory purposes or site-specific decisions is discouraged.

Examples of Use

NOAA Sea Level Rise Viewer

NOAA uses land cover data in its Sea Level Rise Viewer tool, which depicts how a range of sea level rise scenarios could drive saltwater wetlands inland and affect the extents of freshwater

wetlands. The NOAA Sea Level Rise Viewer depicts the extents of inundation from a range of sea level rise scenarios. The tool also displays potential impacts resulting from sea level rise or vulnerability to these impacts. Sea level rise can drive coastal wetlands inland, referred to as marsh migration, and affect freshwater wetlands in inland areas. Using the wetland classifications of the 30-meter resolution land cover data, the Sea Level Rise Viewer provides projections of the change in composition of coastal wetlands as sea levels rise. This tool provides useful insights into the ways sea level rise could affect coastal habitats and ecological functions that provide natural resilience to climate change.

Water Quality Indicator

Land cover data can be used as an input for assessing water quality, which NOAA has demonstrated in the data tool “How to Use Land Cover Data as a Water Quality Indicator.” This tool depicts land cover at watershed scales, with a focus on impervious surface, forests, grasslands, and land cover composition of riparian buffers. In the watershed context, these factors can provide high-level insights into the health of a watershed and potential level of impact to water quality from runoff and pollutants. The technical guide indicates more detailed analysis of water quality impacts can be performed using modelling tools, such as the open-source, GIS-based tool OpenNSPECT, which can be used to identify potential water quality impacts from local development, land uses, and climate change (NOAA 2015).

Capacity and Resources Needed

The development of the 30-meter resolution land cover requires multiple spatial datasets and is informed by many others, including high-resolution imagery. Landsat satellite imagery has served as a fundamental component in the development, but other spatial datasets provide supplemental information about the landscape, which inform the models that classify land cover from imagery. Data that depicts roads or other built environments can help with classification of impervious surfaces. The National Wetlands Inventory (NWI), SSURGO Soils, and National Hydrography Data (NHD) greatly informs the geographic identification and the classification of wetlands and water features. Digital Elevation Models and land use layers are also used for a wide array of information. For example, agricultural land use data and/or the USDA’s Cropland Data Layer can help distinguish pasture/hay land cover from grasslands or shrub, which can often appear similar in imagery and infrared.

NOAA’s land cover data is typically updated every five years. Maintaining this cycle can be challenging, especially as funding and capacity for C-CAP vary. C-CAP is not a line item in the NOAA budget and is not a mandated program. Partnerships with governments that can fund product development are viewed as an important resource for supporting development of the land cover data. The standard cost to produce each update is approximately \$75,000 for the coastal portion of the state and would be roughly \$150,000 for full Washington coverage.

NOAA High-Resolution Land Cover Data

NOAA has been producing limited areas of HRLC data for a number of years but has recently taken steps to transition its national monitoring program from 30-meter to 1-meter mapping. The new HRLC allows for application support at smaller scales and more detailed analysis than possible from the past, coarser (30-meter) mapping. NOAA's current vision is to transition to this higher resolution monitoring over the next several years, and that future updates (post-2025) would be mapped at this same resolution.

Dataset Background and Purpose

Because of the scale (and costs) associated with such a national level transition, NOAA has broken the work up into two phases. The first phase data has been developed for all coastal areas of the United States, outside of the Chesapeake region (Chesapeake data is being developed by the Chesapeake Bay Program, and those states). This [data was released in January of 2024](#) and focuses on three land cover classifications (impervious surfaces, woody canopy, and water features). Areas that do not fall into one of these categories (i.e. bare and/or herbaceous features) were excluded from mapping. The data is based on 2020 or 2021 imagery. State agencies (led by WA TECH) contributed funding in order to ensure that these data would also be available for the eastern portion of Washington state, thereby ensuring full state coverage.



Figure 3-5 Example of NOAA's High Resolution Land Cover Data Products for Impervious, Canopy and Water Cover Types

The second phase of data development has not yet been completed for most coastal areas of the country. This work builds upon the phase 1 impervious, canopy, and water products and builds upon that data. The process involves correcting any systematic errors found in the phase 1 data and then expanding upon that mapping to include additional cover types, land use, and several categories of wetlands. The result includes up to 20 land cover types, that match those mapped nationally as part of NOAA's standard Coastal Change Analysis Program (C-CAP) land cover and that correspond to those identified in the National Land Cover Database (NLCD) and will include the following categories:

- Impervious
- Open Space Developed

- Cultivated Land
- Pasture/Hay
- Grassland
- Scrub Shrub
- Deciduous Forest
- Evergreen Forest
- Palustrine Forested Wetlands
- Palustrine Scrub Shrub Wetlands
- Estuarine Forested Wetlands
- Estuarine Scrub Shrub Wetlands
- Palustrine Emergent Wetlands
- Estuarine Emergent Wetlands
- Open Water
- Palustrine Aquatic Bed
- Estuarine Aquatic Bed
- Unconsolidated Shore
- Barren Land
- Tundra
- Perennial Ice/Snow

While this mapping has not been completed for coastal areas within Washington state, there are several geographies where recent pilot work has been completed. The most recent of these covers the area of the southern Puget Sound and Pierce County (which was work funded by both the US Environmental Protection Agency and the WA Department of Ecology). To access NOAA C-CAP's HRLC data products, visit their website at:

<https://coast.noaa.gov/digitalcoast/data/ccaphighres.html>.

Strengths

The HRLC data retains the strengths of the 30-meter resolution land cover data, while improving upon that data's weaknesses by adding additional spatial detail. The high level of detail associated with mapping of impervious features, as well as the non-impervious cover types within urban areas, is a particular strength. While the 30-meter resolution land cover data had a high level of accuracy at a county-scale, the HRLC data will support a comparable degree of accuracy at more localized scales. This data is currently available statewide, based on 2021 imagery.

The phased approach has allowed for some data to already be made available to the public. By providing the impervious surface, woody canopy, and water features now users are able to utilize these key indicators in their work. When the subsequent phase of expanded scheme mapping is complete, the addition of more detailed land use and wetlands categories will be of even greater benefit and should provide distinct benefit to state level effort to track agricultural use and wetlands related change (as well as an explicitly connect to the USFWS National Wetland Inventory). In fact, such work to co-develop land cover, NWI, and 3DHP has already been occurring in WA (effort currently lead by Josh Greenberg, the state NHD coordinator).

The high-resolution data will support and improve upon past work to identify change in land cover over time. The initial phase of the HRLC dataset will be especially important for monitoring land cover change, as the classifications of impervious surface, canopy, and water or wetlands, are key indicators of changes to the built and natural environment.

Allowable Uses and Restrictions

The HRLC data is designed to be applicable to a wide range of uses, similar to the 30-meter resolution data. However, due to the data being developed with Ecopia's proprietary high-

resolution dataset, the data may not be used for training computers in land cover classification for five years after the publication of the data.

Examples of Use

Costs and limited capacity can present barriers to developing HRLC datasets. Partnerships with agencies that have the budget or mandate to support development of high-resolution data have been a major driver in the application of HRLC data.

New Hampshire Salt Marsh Plan

NOAA partnered with the Great Bay National Estuarine Research Reserve of New Hampshire to develop HRLC data for the region. The resulting data classified and mapped 12 land cover categories (compared to the currently available high-resolution data with only three classifications). This dataset was generated with high-resolution imagery, LiDAR, and field data. High-resolution wetland mapping allows for more informed decision-making at a localized scale, which cannot reliably be performed with lower resolution land cover data. The resulting land cover data helped to assess the conditions of salt marshes, vulnerability to climate change, and adaptive capacity, which further informed the recommended strategies in New Hampshire's Salt Marsh Plan (NOAA 2021).

Charleston, South Carolina Urban Heat Island Assessment

NOAA partnered with the City of Charleston to better understand the geographic variation of urban heat island effects. The high-resolution data supported identification of individual trees and small groups of trees in urban environments, as well as the extents of impervious surface. The land cover data was analyzed alongside demographic data and temperature data from throughout the city to identify inequities in the distribution of tree canopy across the city. This project also helped to identify where urban heat island impacts could disproportionately affect vulnerable populations (NOAA 2023).

Capacity and Resources Needed

The creation of HRLC data has similar challenges to past NOAA efforts, including the lack of a designated budget or mandate, time and worker capacity constraints, and reliance on other datasets. Early development of the high-resolution data was supported by an influx of funding, but year-to-year funding will remain uncertain, which could impact future updates to the data. Much of the HRLC data has involved contracting with private firms that can provide higher-resolution data and adapt it to the needs of C-CAP. Partnerships with state or other federal agencies that can help fund or support the development of the HRLC data will be a crucial need for continuing to develop and maintain the data. The cost associated with the development of phase 1 (impervious, canopy, and water) products statewide was approximately \$600,000. Future updates would be expected to be similar in price. The cost estimated to complete phase 2 mapping would be an additional \$1.5M for all coastal areas or \$3.0M for coverage of the full state.

Related C-CAP Data Products

NOAA, or its private sector contractors can perform further mapping production to create additional, customized data products. These products can provide higher levels of detail, while still having the benefit of leveraging and being related to the C-CAP standard product line.

Impervious Feature Mapping

For additional cost, NOAA can facilitate the mapping of more detailed impervious and developed feature types. Categories can include (but may not be limited to) buildings, roads, bridges, railroads, driveways, sidewalks, crosswalks, parking lots, sports fields, and swimming pools. This type of data was purchased for state agency use in Washington state.

Wetland Feature Mapping

Salt Marsh Habitat mapping is also a possibility available by working with NOAA, and/or through our contractors. This data adds additional detail to commonly mapped wetland features, that can be used for more detailed habitat assessment. Common categories mapped to date include Pannes, Pools, Phragmites, and more. This data can be highly useful for evaluating change impacts due to climate.

SECTION 4

Assessment

The datasets for this assessment were identified and selected for evaluation by ESA in conjunction with the PSEMP SDWG Co-chairs (PSP, Northwest Indian Fisheries Commission, WDFW) (see **Table 4-1**). This includes 1m WDFW HRLC and NOAA 1m C-CAP HRLC data, looking specifically at woody vegetation and impervious surface cover types. Additionally, we evaluated the WDFW HRCD products and NOAA’s 30m C-CAP 2011-2016 change detection products. As part of this process, we coordinated with the Washington Department of Ecology on the status of the updates to the NWI data layer and relationship to other hydrologic data products.

TABLE 4-1
DATASETS EVALUATED AS PART OF ASSESSMENT

Name	Description	Coverage	Year
WDFW 1m HRLC	High-resolution data based on NAIP imagery, periodically updated at county and watershed scales. Land cover classes include three height-based vegetation cover types, built, gravel, ground, and water.	Western Washington, select central and eastern Washington counties	2017, 2021
NOAA C-CAP 1m HRLC Phase 1	High-resolution data based on NAIP and other imagery with three cover types: impervious surfaces, woody canopy, and water,	Statewide	2021-2022
NOAA C-CAP 1m HRLC Phase 2	High-resolution data with up to 20 categories of land cover, including several categories related to land use and wetlands. This data expands upon the phase 1 products.	Available in pilot areas only, including Snohomish, Pierce, Kitsap, and portions of Thurston, Mason, and Jefferson Counties	2015, 2017
WDFW HRCD	Intended to help monitor and assess trends in land cover change over time. These changes primarily include significant loss of tree cover or areas that have been converted to “permanent” human use (i.e. roads, buildings), with identification of cause and time period of change.	Western Washington, select central and eastern Washington counties	2006-2021
NOAA C-CAP 30-meter land cover and change	30m resolution data updated to reflect land cover changes for 25 land cover types, at ~5-year increments. Supports analysis of change in acreage and percentage of cover types.	Western Washington	1992-2016 (2021 planned)
Snohomish County 1m HRLC	1m resolution data that includes six land cover categories.	Snohomish County	2021

Interviews were conducted with data providers, including NOAA and WDFW, to glean insights into how the datasets were developed, common use cases, frequency of product updates, challenges and limitations with the data, and other elements. The Puget Sound region was our

primary focus area. We employed a stratified random sampling approach to three selected Counties: Clallam, Snohomish, and Thurston and based on landform characteristics, level of development (urban/rural/natural) and inclusion of representative samples of agricultural lands, riparian areas, and wetlands. This approach was enriched by the inclusion of targeted large restoration projects within these counties: Qwuloolt, Elwha, Dungeness, and Nisqually River projects. The geographical scope encompassed four 1-square mile hexagons and three USGS HUC12 watersheds, ensuring a comprehensive representation of the region's varied landscapes. **Figure 4-1** shows the assessment locations for the three counties in the Puget Sound region.

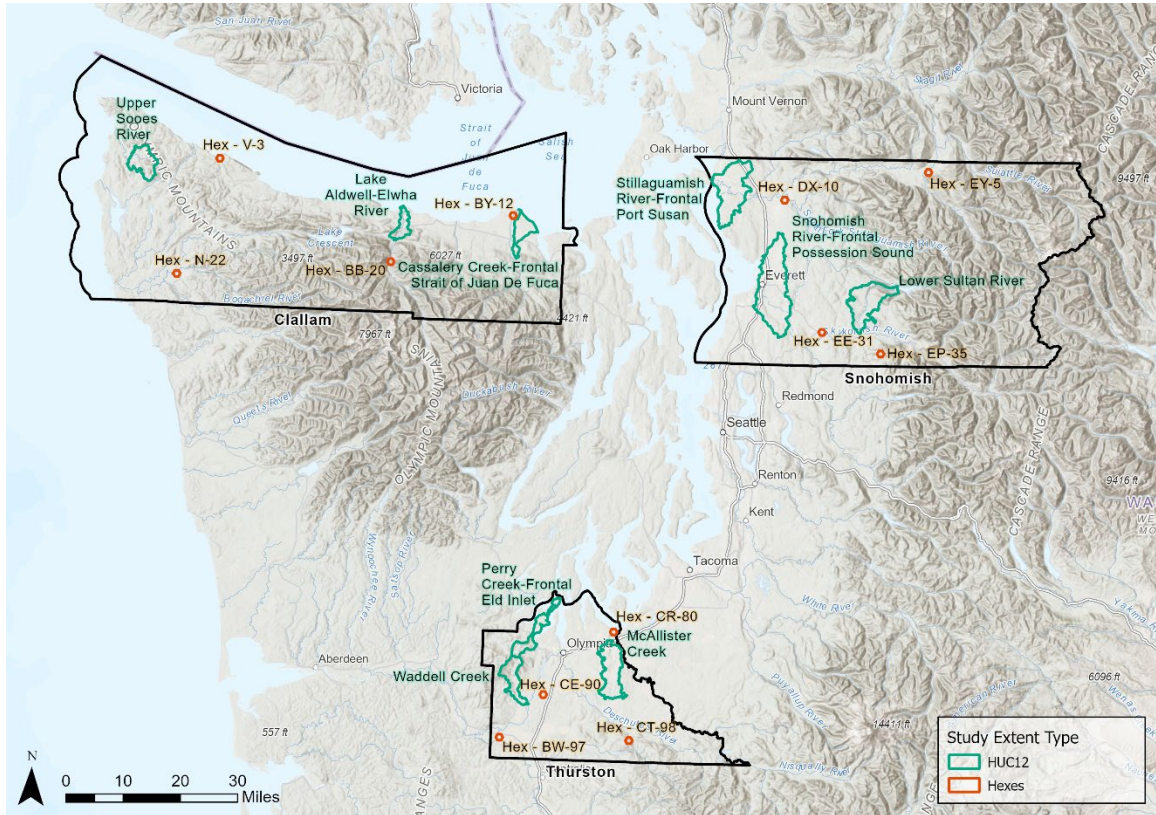


Figure 4-1 Puget Sound Assessment Locations

Our analysis employed a visual assessment methodology, comparing the selected HRLC datasets against base imagery that matched the year of the data to evaluate the accuracy of impervious and woody vegetation classifications. This comparative analysis aimed to identify the overall quality of the data products and any tendencies of the datasets to over or underrepresent actual on-the-ground conditions. Each location's analysis was underpinned by a set of summary statistics, including total acres and percentages by cover type, providing a quantitative foundation for our evaluations.

The evaluation process entailed an examination of the strengths, limitations, and trade-offs inherent in each dataset. From this assessment, we provide potential applications of these datasets in habitat restoration and management efforts, including specific guidance on dataset utilization,

analysis workflows, and methodologies tailored to the needs of habitat restoration practitioners, geospatial analysts, natural resource managers, and associated stakeholders.

For the change detection products, we similarly performed a visual assessment and prepared a set of summary statistics for the assessment locations.

Results and Findings

This section provides a summary of our results and findings including detailed look at the assessment locations for three counties in the Puget Sound region that can be found in **Appendix A**.

Overall Results and Summary

The land cover assessments for the 2017 WDFW HRLC and the 2021 1-meter C-CAP data present both strengths and weaknesses of the data products.

For the 2017 WDFW HRLC, strengths lie in the detailed land cover data, which includes polygons and canopy height statistics, such as modeled height, average height, maximum height, and minimum height. These details offer a precise understanding of the vegetation structure and can be important for natural resource management and environmental monitoring applications. Furthermore, the inclusion of land cover NDVI polygons statistics is another asset, providing insight for forest assessments. Another significant strength is the temporal component of the dataset, which aims to provide updates on a two-year cycle.

However, the weaknesses of the 2017 WDFW HRLC include an overrepresentation or confusion of impervious surfaces in certain areas. This could lead to inaccuracies in impervious measurements and use in other land use planning assessments. Additionally, there is a noted confusion between built areas and gravel, particularly in stream areas, which could affect some hydrological studies and ecological assessments of these habitats.

The 2021 1m C-CAP shows a strong correlation of impervious and water features with the 2021 NAIP imagery, indicating high accuracy for these cover types. There is also a noted low level of confusion between impervious and semi-impervious features, and it consistently reports less impervious surface area compared to the HRLC by 4% (7,370 acres) for all areas in our assessment which is largely associated with additional detail of impervious and non-impervious distinctions inside of urban environments.

Despite these strengths, the 2021 1m C-CAP also has some limitations. The public data product is currently restricted to water, impervious, and canopy cover types, which leaves other land cover types unaccounted for, resulting in gaps in coverage. While these gaps are envisioned to be addressed as part of NOAA's second phase, that mapping has yet to be completed.

The 2017 WDFW HRLC and the 2021 1m C-CAP both have their unique strengths and weaknesses (see **Table 4-2**). The WDFW HRLC offers detailed vegetation structure and temporal change detection capabilities but has some constraints associated with the impervious mapping.

In contrast, the C-CAP aligns well with high-resolution imagery for impervious, water and most vegetation areas but lacks comprehensive coverage and detailed statistics. These datasets both serve as valuable resources and can be complementary to one another for various land management applications.

TABLE 4-2
DATASETS STRENGTHS AND WEAKNESSES SUMMARY

Dataset	Strengths	Weaknesses	Common Applications
WDFW 1m High Resolution Land Cover (2017)	Tree canopy cover type includes canopy height statistics (modeled height, Avg, min, max and NDVI), supports multiple vegetation classifications, and generally correlates well with base imagery.	Over-representation of impervious surfaces in some areas. Built/gravel confusion in stream areas and confusion between bare ground and short vegetation.	Natural resource management - tree canopy assessments, riparian assessment, watershed conditions/management, and natural environment change detection and monitoring.
NOAA C-CAP 1m Land Cover (2021)	Impervious and water features show strong correlation with 2021 imagery, supporting enhanced wetland identification. Vegetation layer also strong in most areas, particularly urban environments	Public 1m data product limited to water, impervious and (woody) vegetation cover types leaving gaps in coverage (until phase 2 mapping is completed).	Urban planning, stormwater management planning, hydrologic assessments, and supporting modeling and analysis.

Detailed Results

Land Cover

For each extent, we prepared a side-by-side comparison of the land cover outputs with the base imagery along with summary statistics for total acres and percent for each cover type (see **Figure 4-2**). Additionally, a general observations section provides insights for each location.

See Appendix A for these detailed results.

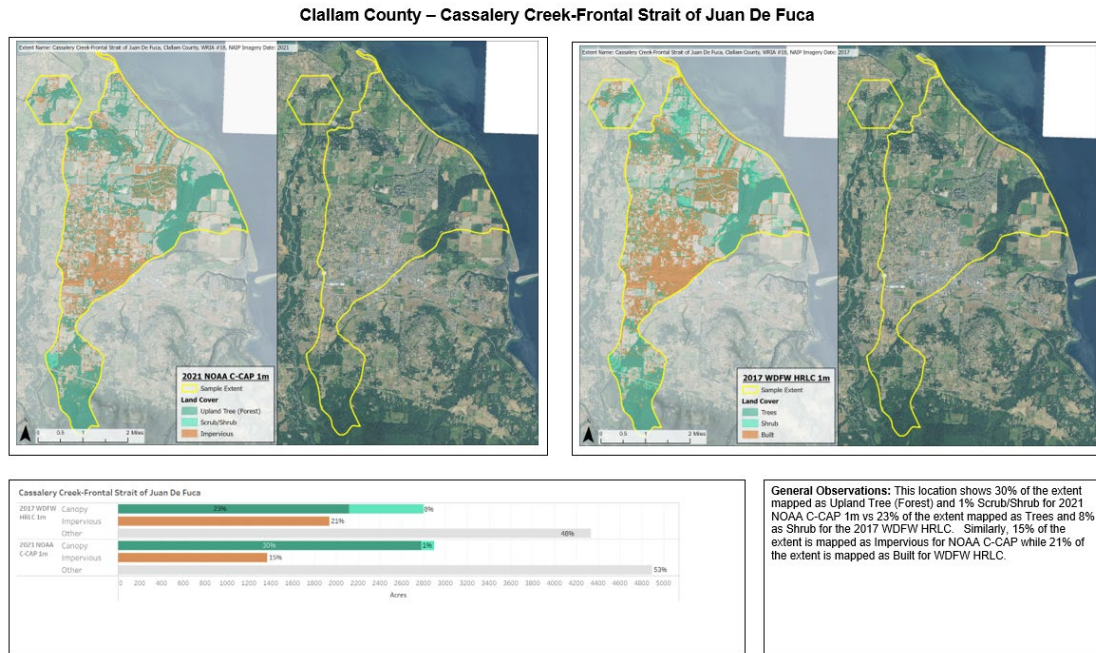


Figure 4-2
Assessment Location Detailed Results

Change Detection

WDFW High Resolution Change Detection

WDFW's change detection product shows a strong correlation with anthropogenic and natural changes when compared to imagery for time stamps (see **Figure 4-3**). Human technicians review every polygon identified as an area of change and assign a cause of the change, which contributes to the accuracy and reliability of the data. The identification of the cause of land cover changes is a unique attribute for this dataset and is valuable for assessing the source and scale of environmental changes. If the product is updated relatively frequently, it provides data managers with the ability to quantify changes at more frequent intervals and attribute changes to natural or non-natural causes.

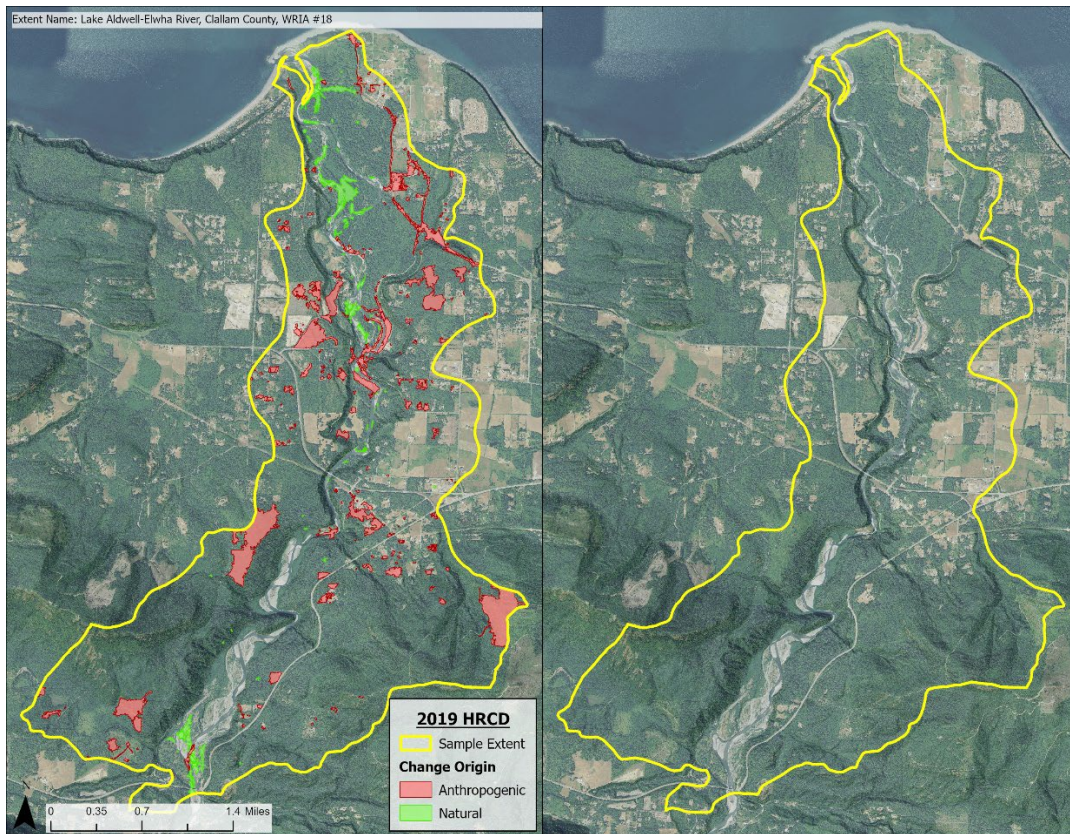


Figure 4-3

WDFW High-Resolution Change Detection for Lake Aldwell-Elwha River in Clallam County

This product is a higher resolution than other change detection products, which allows for more granular analysis of the areas experiencing change (see **Table 4-3**). However, WDFW's HRCD data identifies only three types of land cover changes (decrease in tree canopy, increase in impervious surface, and increase in semi-pervious surface). A limitation of the WDFW's product is the inability to track gains from ecological restoration, such as increases in tree canopy or decreases in impervious surface. While previous releases of the data identify an initial land cover attribute for areas of change, the classifications of this attribute in the HRCD data are not compatible with other land cover datasets, limiting the potential for further analysis.

TABLE 4-3
WDFW HIGH-RESOLUTION CHANGE DETECTION SUMMARY STATISTICS FOR ASSESSMENT LOCATIONS

2019 HRCD	Column Labels		Anthropogenic		Natural		No Change		Total Sum of Acres
	Sum of Acres	% of Extent	Sum of Acres	% of Extent	Sum of Acres	% of Extent	Sum of Acres	% of Extent	
Clallam	2,589.2	9%	94.4	0%	27,519.5	91%			30,203.1
Cassalery Creek-Frontal Strait of Juan De Fuca	254.8	3%	0.3	0%	8,831.4	97%			9,086.5
Hex - BB-20	0.9	0%	16.6	3%	624.8	97%			642.3
Hex - BY-12	2.2	0%	0.6	0%	637.3	100%			640.0
Hex - N-22	29.7	5%	0.1	0%	610.2	95%			640.0
Hex - V-3	33.8	5%	4.8	1%	601.4	94%			640.0
Lake Aldwell-Elwha River	362.9	6%	71.7	1%	5,885.9	93%			6,320.5
Upper Sooes River	1,904.9	16%	0.3	0%	10,328.5	84%			12,233.8
Snohomish	6,900.2	7%	105.0	0%	94,107.1	93%			101,112.3
Hex - DX-10	11.6	2%	0.0	0%	628.7	98%			640.3
Hex - EE-31	50.0	8%		0%	591.7	92%			641.8
Hex - EP-35	373.9	51%	0.7	0%	352.7	48%			727.3
Hex - EY-5	2.2	0%	55.2	9%	583.5	91%			640.8
Lower Sultan River	2,953.7	13%	27.3	0%	20,551.5	87%			23,532.5
Snohomish River-Frontal Possession Sound	2,467.4	5%	14.6	0%	43,302.5	95%			45,784.5
Stillaguamish River-Frontal Port Susan	1,041.4	4%	7.3	0%	28,096.5	96%			29,145.1
Thurston	3,027.7	7%	65.0	0%	40,646.2	93%			43,738.9
Hex - BW-97	6.5	1%	0.5	0%	633.3	99%			640.3
Hex - CE-90	3.0	0%		0%	637.0	100%			640.0
Hex - CR-80	18.8	3%	1.0	0%	621.5	97%			641.3
Hex - CT-98	105.2	16%	0.1	0%	540.5	84%			645.8
McAllister Creek	1,256.6	6%	20.3	0%	18,291.6	93%			19,568.4
Perry Creek-Frontal Eld Inlet	873.7	9%	38.3	0%	9,306.5	91%			10,218.5
Waddell Creek	764.0	7%	4.8	0%	10,615.8	93%			11,384.6
Grand Total	12,517.1	7%	264.4	0%	162,272.8	93%			175,054.3

NOAA C-CAP Change Detection (2011-2016)

NOAA's C-CAP Change Detection data product depicts changes at a 30-meter scale from one land cover type to another between time stamps. This data was updated for western Washington to depict land cover changes from 2011 to 2016, with past land cover change data provided for approximately five-year intervals dating back to 1992. A 2021 update is currently planned but has been delayed and is not expected to be complete until the end of calendar year 2024.

Notable land cover classifications that are unique for NOAA's change detection product include water and wetlands, agriculture, and non-forest vegetation. NOAA's change detection product has more land cover classifications change categories than WDFW's but can be difficult to work with for users not experienced in raster data formats only as this product only provides pixel-based changes between time stamps. While the 30-meter Regional Land Cover data could be used from two time stamps to quantify total change for more cover types, the advantages of the NOAA's change detection product are that it provides specific locations where changes in pixel values occurred (see **Figure 4-4**). One of the biggest strengths of the 30-meter C-CAP is the extended time series of data it provided and allows users to evaluate changes in cover types for a specific geography in Washington State between 1996–2016.

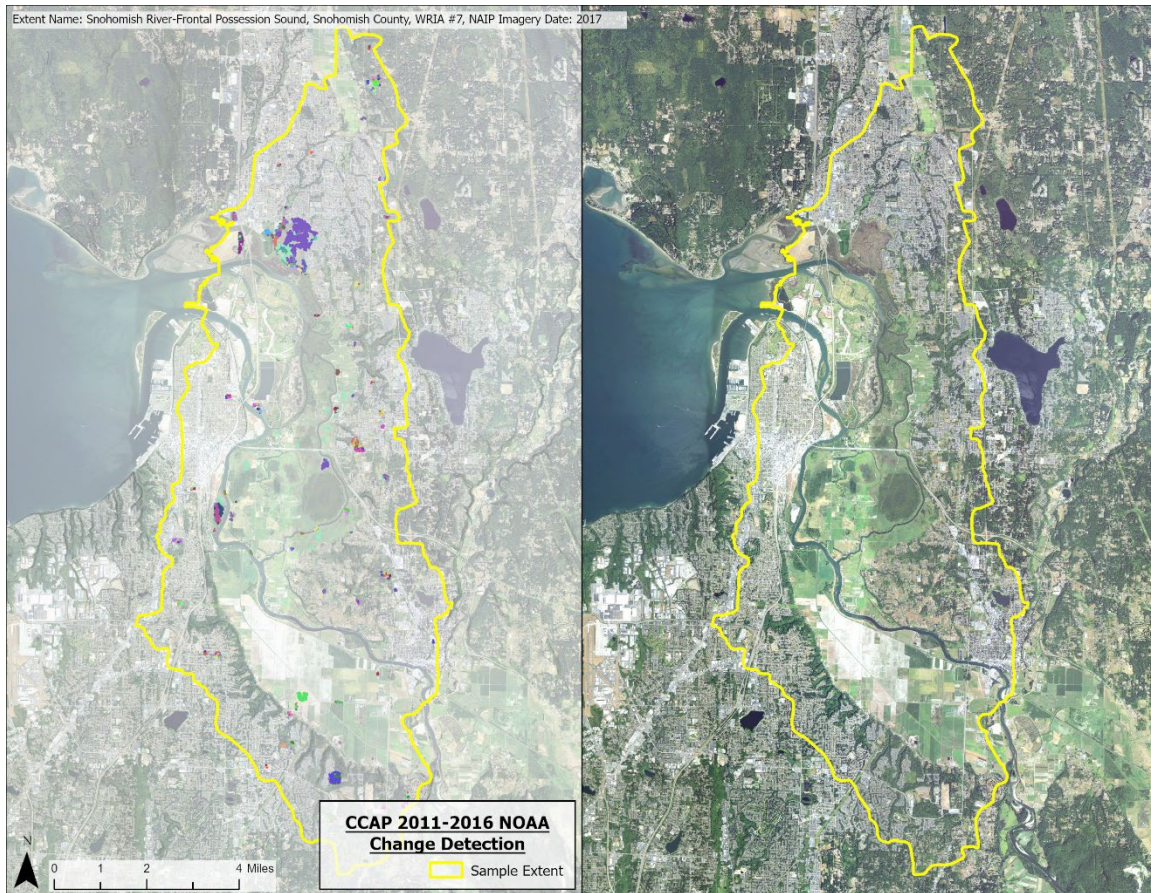


Figure 4-4 Example of NOAA C-CAP 2011-2016 Change Detection for the Snohomish River-Frontal Possession Sound Watershed in Snohomish County

NOAA C-CAP Atlas (1992 – 2016)

The NOAA C-CAP Atlas provides a comprehensive tool for viewing land cover changes over time, specifically from 1992 to 2016, in Washington state. This interactive atlas enables users to examine changes at both county and watershed scales, offering detailed insights into land cover dynamics. To view the C-CAP Atlas, visit their site at: <https://coast.noaa.gov/ccapatlas/>.

Additional Datasets Evaluated

2021 1m Snohomish County

- This dataset was developed by Snohomish County. Land cover in this dataset is classified into seven cover types: bare land, deciduous forest, evergreen forest, impervious, pasture/grassland, scrub/shrub, and water.
- The dataset distinguishes deciduous and evergreen forest types (where WDFW identifies both as trees), and the WDFW data distinguishes gravel from ground (where Snohomish County only identifies bare land) (see **Figure 4-5**).
- This dataset is consistent with identification of impervious surfaces, although shows less accuracy when distinguishing bare ground (which may be semi-pervious gravel) from pasture/grasslands.

- This dataset is consistent with identification of impervious surfaces, although shows less accuracy when distinguishing bare ground (which may be semi-pervious gravel) from pasture/grasslands.

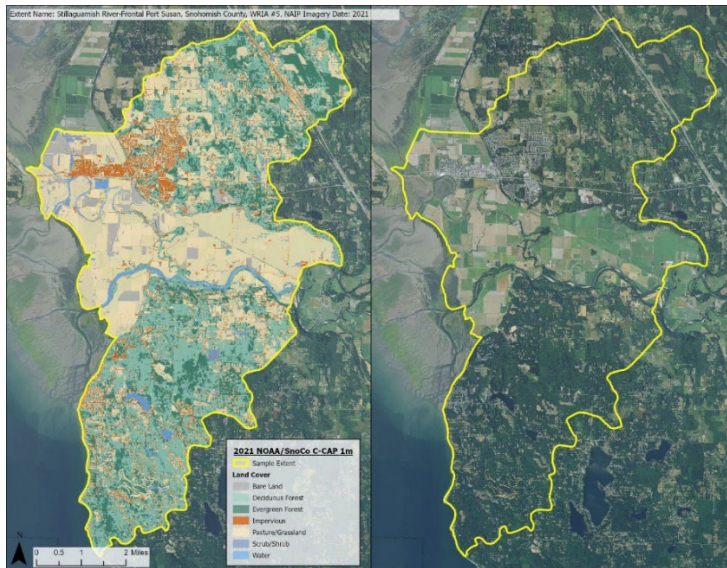


Figure 4-5 Example of NOAA C-CAP 2021 HRLC for the Stillaguamish River-Frontal Port Susan Watershed in Snohomish County

2021 1m WDFW HRLC

- As of 2024, WDFW is working on completing and releasing their 2021 1m HRLC data product as shown in the example map for Thurston County (Figure 4-6) below.
- For the latest on data availability and access, check out their product website at: <https://hrcd-wdfw.hub.arcgis.com/pages/land-cover>.

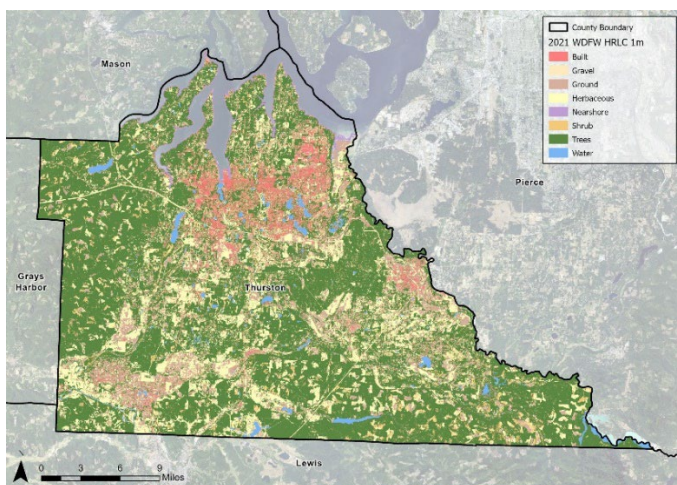


Figure 4-6
Example of 2021 WDFW 1m Land Cover for Thurston County

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SECTION 5

Other Land Cover Datasets and Related Products

Introduction

Beyond NOAA and WDFW, other public agencies, as well as private companies, develop land cover data and supporting products that can be used for similar planning purposes as the NOAA and WDFW land cover data. While these other datasets have unique benefits, such as greater geographic extents or greater focus on specific attributes when compared to the NOAA and WDFW data, they also have limitations that can include lower resolution, lower accuracy, or licensing restrictions.

Ecology Statewide Wetland Mapping Inventory

Ecology conducted a statewide mapping inventory effort aimed at assessing wetland mapping efforts across Washington. This effort included participants from local, tribal, and federal agencies as well as land managers. Key findings revealed that most users rely on NWI maps, but there is a need to update those maps. Wetland spatial data varies, often derived from NWI data with field-verified support. Digitizing field-verified data would standardize wetland spatial data and support future NWI updates. The project emphasized collaboration and communication among wetland stakeholders. For more details on this project, visit their website at:

<https://ecology.wa.gov/water-shorelines/wetlands/tools-resources/mapping-resources/map-inventory-project>.

National Land Cover Database

The National Land Cover Database is a 30-meter resolution land cover dataset developed by the U.S. Geological Survey in collaboration with other federal agencies. The data covers the entire contiguous United States, Hawaii, Alaska, and Puerto Rico. The NLCD has 16 land cover classifications used nationwide, plus four that are only used in Alaska. The land cover classifications have significant overlap with those of NOAA's 30-meter resolution land cover data, with the major differences being the NLCD's Alaska-specific herbaceous and shrub classifications and the C-CAP land cover's six wetland classifications (compared to NLCD's two wetland classifications). The U.S. Geological Survey and its federal partners develop numerous data products related to the NLCD, including urban impervious surface, land cover change, and tree canopy data (USGS 2018).

The NLCD is updated every two to three years. Nine iterations of the NLCD were developed between 2001 and 2021. The iterations are directly comparable and support land cover change analysis. For more details on this dataset and to download the data, visit the website at:

<https://www.usgs.gov/centers/eros/science/national-land-cover-database>.

Esri/Microsoft Sentinel-2 10m Land Cover

The Esri/Microsoft Sentinel-2 10-meter Land Cover is a global dataset derived from publicly available satellite imagery collected by the European Space Agency. The land cover data is developed from this imagery with proprietary AI geospatial modelling, which is informed by substantial human-identified land cover data. The data is grouped into nine broad land cover classes: water, trees, flood vegetation (such as wetlands), crops, built area, bare ground, snow/ice, clouds (land cover undetermined), and rangeland (such as grasslands and some agriculture). The average accuracy of the data is estimated to be 75%, which is lower than most land cover categories or datasets produced by NOAA or WDFW (Microsoft 2024).

The data has been updated annually since 2017. It is made available for public viewing through ESRI and Microsoft but requires licensing to manipulate and analyze. To view details and access this dataset, visit the ArcGIS details page at:

<https://www.arcgis.com/home/item.html?id=cfcfb7609de5f478eb7666240902d4d3d>.

Microsoft US Building Footprints

Microsoft US Building Footprints is a dataset that depicts polygons for identified building footprints nationwide. The buildings footprints are derived from multiple data sources but are largely based on computer learning models that can identify buildings from high-resolution satellite imagery. The data has few attributes but does identify the area of building footprints. The data has a high level of accuracy, but the accuracy can vary depending on the complexity of the environment and recency of the imagery on which it is based. Data is updated more frequently for areas of the United States with a higher intensity or concentration of development are, while more rural areas may depict footprints from satellite data as old as 2012 (Microsoft 2023). To view details and download this dataset by state, visit the Microsoft GitHub page at:

<https://github.com/Microsoft/USBuildingFootprints>.

Open Street Map

OpenStreetMap (OSM) is a comprehensive, open-source dataset that provides detailed geographic information through a collaborative mapping project. The data includes a wide array of features such as roads, buildings, land use, natural features, and more. Unlike datasets derived from specific data sources or technologies, OSM data is contributed by a global community of volunteers and is continuously updated, ensuring a high level of detail and current information. The dataset is versatile, supporting various applications from urban planning and navigation to environmental analysis and disaster response. However, the accuracy and completeness can vary depending on the level of local contributor activity. OSM data is freely accessible and can be viewed or downloaded from the OpenStreetMap website at <https://www.openstreetmap.org>.

TABLE 4-4
SUMMARY OF OTHER LAND COVER DATA PRODUCTS AND RELATED DATASETS

Dataset	Coverage	Resolution	Intended Use	Data Characteristics	Local Scale Support
Ecology Statewide Wetland Mapping Inventory	Washington State	Varies (field-verified)	State-level	Derived from NWI data, field-verified, collaborative effort among stakeholders	Supports detailed local assessments
NLCD	United States	30 meters	Regional and national scale	16-20 land cover classifications, supports change analysis, developed by USGS	Moderate detail, useful for regional trends
Esri/Microsoft Sentinel-2 10m Land Cover	Global	10 meters	Global scale	9 land cover classes, AI geospatial modeling, updated annually, average accuracy of 75%	General insights, less detailed locally
Microsoft US Building Footprints	United States	High-resolution	Nationwide building footprints	Polygons derived from high-resolution satellite imagery, updated frequently in urban areas	High accuracy for urban planning
OSM	Global	Varies	Versatile, wide array of uses	Community-contributed, continuously updated, includes roads, buildings, land use, natural features	Highly detailed, depending on local activity

Others

The NOAA and WDFW land cover datasets, as well as the other data products described above, are some of the most commonly used geospatial resources for assessing land cover and derivative products. Due to the wide accessibility and high level of accuracy of previously described datasets, other options may have greater limitations or may be more focused on particular attributes that could affect their usefulness.

Other land cover datasets that are currently or have historically been used for planning in the United States include:

- **GAP/LANDFIRE National Terrestrial Ecosystems Data:** This dataset depicts ecosystems in the United States at 30-meter resolution, with a granular level of classification that includes 680 ecosystem classifications and 28 land use classifications based on information that includes vegetation, hydrology, and soils. The data has not been updated since 2011 (USGS 2019).
- **Forest Inventory and Analysis Land Resources:** This product consists of a combination of datasets and data tools that depict vegetative land cover, losses and gains in forest, tree canopy, and forest health assessments. Changes in these data can be viewed in the Landscape

Change Monitoring System for years ranging from 1985 to 2022 (United States Forest Service 2022).

- **European Space Agency Climate Change Initiative Land Cover Project:** This data depicts global land cover at 300-meter resolution. The land cover is classified using the United Nations Land Cover Classification system, which has 22 classes, plus numerous sub-classifications that provide more specific details on vegetative land cover. The Land Cover Data is available from 1992 to 2015 and supports change monitoring (European Space Agency 2020).
- **USDA Cropland Data Layer:** The USDA Cropland Data Layer (CDL) is a high-resolution, geospatial dataset that provides annual crop-specific land cover and usage across the United States. With a resolution of 30 meters, the CDL offers detailed classifications for major crop types and other land cover categories, derived from satellite imagery and extensive ground-truthing. The dataset is updated annually, enabling the tracking of changes in agricultural patterns and supporting a wide range of applications, including agricultural monitoring, land management, and environmental assessment. The CDL is recognized for its high accuracy, particularly in areas with intensive agricultural activity. For more details and to access the data, visit the USDA NASS CDL website at:
https://www.nass.usda.gov/Research_and_Science/Cropland/Release/index.php.

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SECTION 6

Guidance and Recommendations

Guidance for Practitioners

Each cover data product evaluated in this report has strengths or unique characteristics that would be beneficial for various uses that could benefit Puget Sound recovery. Among high-resolution land cover data products, the 2017 WDFW HRLC data has clear advantages in its potential for multiple uses and statistical analysis (due to the inclusion of canopy statistics, canopy polygons, and time stamp data), while the 2021 1-meter C-CAP data was generally found to be more accurate overall when compared to base imagery, particularly with impervious surface and water feature mapping. The strengths of WDFW's canopy data could provide meaningful insights into key habitat indicators, but its use for assessing a wider range of habitat conditions could be limited by the data's overrepresentation of impervious surface and confusion of in-stream gravel for built environments. Despite the higher accuracy of the 2021 1-meter C-CAP product, its potential for thorough analysis of environmental conditions is currently limited by its identification of only three cover types (impervious, water, and canopy) but will include up to 20 categories of land cover, including several categories related to land use and wetlands when the Phase 2 product is available.

For change detection data products, the WDFW HRCD data is a valuable data product for assessing changes in land cover over time, particularly new development, and tree loss in areas. We found WDFW's HRDC data to be more accurate, higher resolution, and identifies changes over shorter time periods when compared to the NOAA C-CAP 2011-2016 product. Human verification of change areas and the cause of change for the HRCD could be a notable advantage in WDFW's process that would be difficult to scale to a national program like C-CAP.

- Based on these findings, WDFW's data products may be best utilized for natural resource management assessments that focus on vegetation (especially tree canopy) and land cover changes that in support of habitat protection or restoration. While the HRCD product is highly accurate in detecting changes, including increases in impervious or semi-pervious surface, the 2017 WDFW HRLC data has weaknesses in its ability to distinguish impervious and semi-pervious surfaces, most notably the confusion between gravel near streams and built environments. Making this distinction is critical for assessing riparian and floodplain habitat conditions and, as such, the 2017 WDFW HRLC data may not be the optimal dataset for quantifying total impervious and semi-pervious coverage. However, the HRLC data's inclusion of multiple vegetation cover types and vegetation height statistics is useful for assessing natural conditions in riparian and other natural habitats.
- Although currently limited to impervious, canopy and water, The 2021 1-meter C-CAP product can be used to serve a variety of applications, from environmental management and risk assessment to urban planning and conservation. The impervious surface cover type, in

particular, can be useful for assessments in the built environment. More specifically, the C-CAP product would have advantages over the WDFW HRLC data for assessments in mixed natural and built environments or planning related to stormwater management and water quality.

Gaps

The NOAA C-CCAP and WDFW Land Cover data products, while critical data sources and inputs for environmental monitoring, modeling, land use planning, and resource management applications, present some gaps in certain facets that can make it challenging for practitioners to rely on these datasets on a consistent basis. A primary challenge is the lack of comprehensive geographic coverage, as both datasets do not encompass all areas either in the Puget Sound or statewide in Washington. Furthermore, the lack of consistent time intervals for the data availability presents challenges, particularly for tracking land cover changes and assessing trends over time. The 1m HRLC C-CCAP dataset, specifically, is limited to a smaller number of cover types that are identified in its traditional 30m resolution product, reducing its utility for detailed land cover analysis. These gaps highlight the need for targeted investments in programs to expand geographic coverage, improve the frequency and timeliness of updates, and enhance the detail and comprehensiveness of land cover classifications, ensuring these datasets can more effectively support environmental management and policy-making.

Recommendations for Investment in Programs

Based on the findings of this project, we recommend funding both programs, as their datasets are complementary. This section is specific to publicly available data sources. However, there are licensing agreements with NEP programs and the state that, if funds are available, allow for different uses. Details for these investments are described below:

- Washington State should invest in WDFW's HRLC and change detection products. These data products have high value applicability for recovery in the Puget Sound region and statewide. Funding the program to allow for consistent and timely updates to both data products would increase their usability for planning and tracking purposes. As a rough estimate, the program should be funded at a level of \$2 million to \$3 million for every 4-year period to produce high quality land cover and change detection for the state.
- EPA and the State should invest in NOAA's high-resolution C-CAP program. The high-quality land cover data, particularly for the built environment, is a valuable resource for Puget Sound and would be for other National Estuary Program areas around the country. Funding levels should be identified in collaboration with NOAA and should be set at a level that is sufficient to produce timestamp updates at a consistent and timely pace. As a rough estimate, NOAA's high-resolution C-CAP program would need \$2.1 million for all coastal areas and \$3 million for coverage for the full state for each cycle. Up-to-date mapping of wetlands and water are critical resources for natural resources management, adding significant value to these datasets.

It is also worth noting that synchronizing the delivery timing of these data products would significantly enhance their utility for end users. Coordinated release schedules would allow users to more effectively integrate and apply the complementary datasets, thereby maximizing the benefits and insights derived from their use.

Furthermore, we recommend that the two efforts and related products should explore the possibility of better coordination. By seeking to align their efforts more closely, the programs can identify and eliminate any redundant activities, leading to a more efficient use of resources. This coordinated approach could potentially lower the overall funding requirements while still achieving high-quality, comprehensive land cover data. Finally, closer coordination between programs will strengthen both products, providing a more seamless and comprehensive dataset for users, ultimately delivering better combined outcomes.

SECTION 7

References

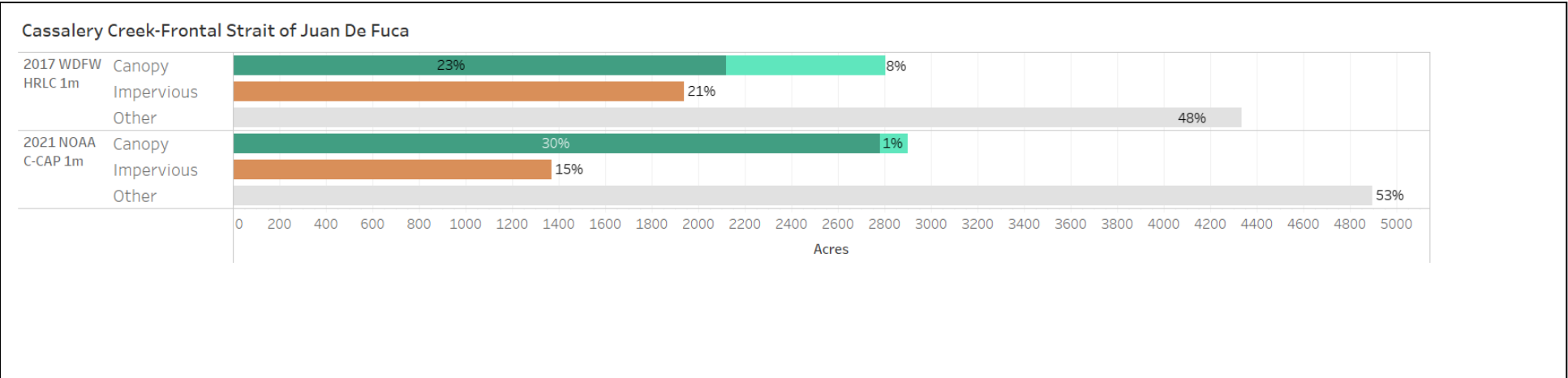
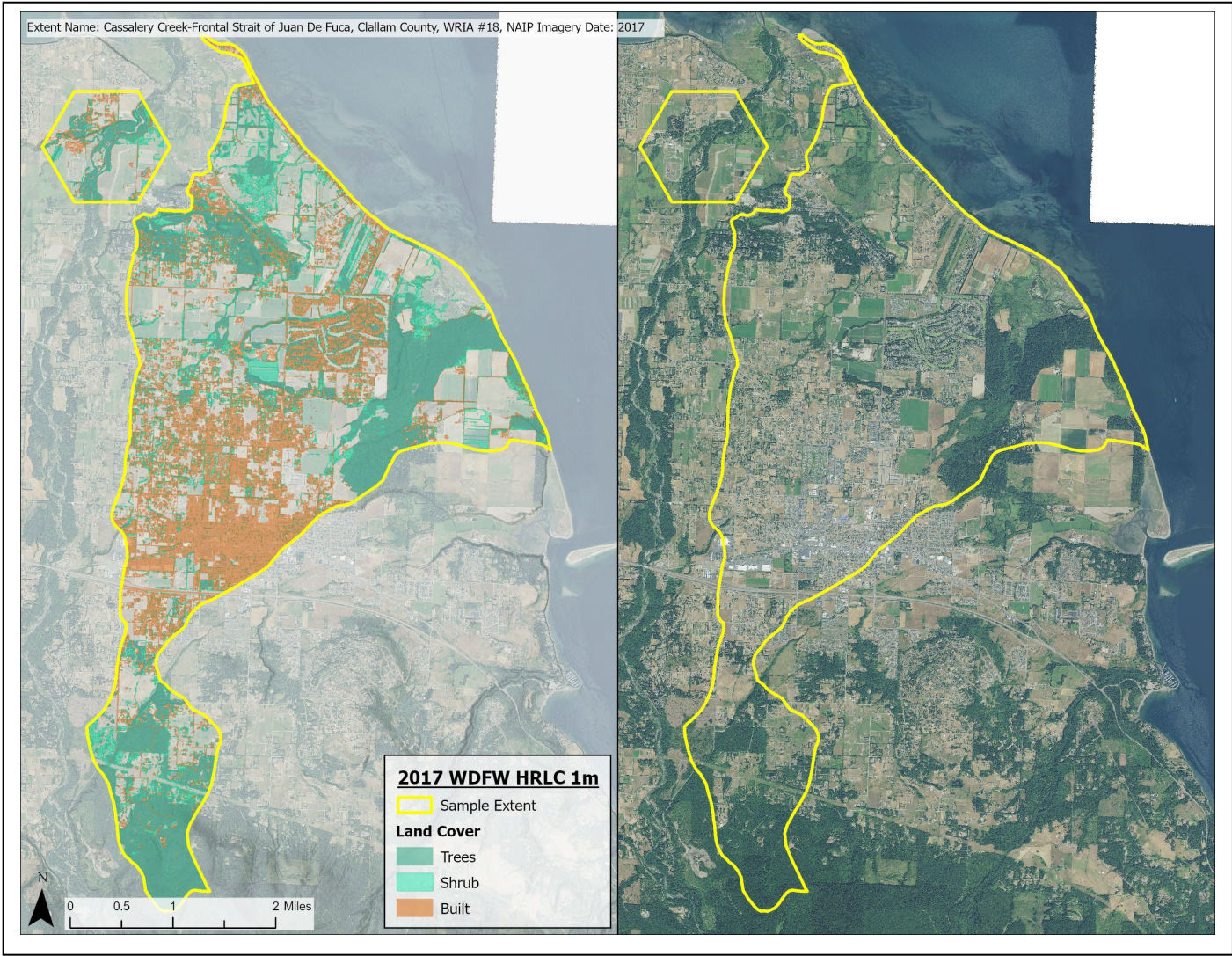
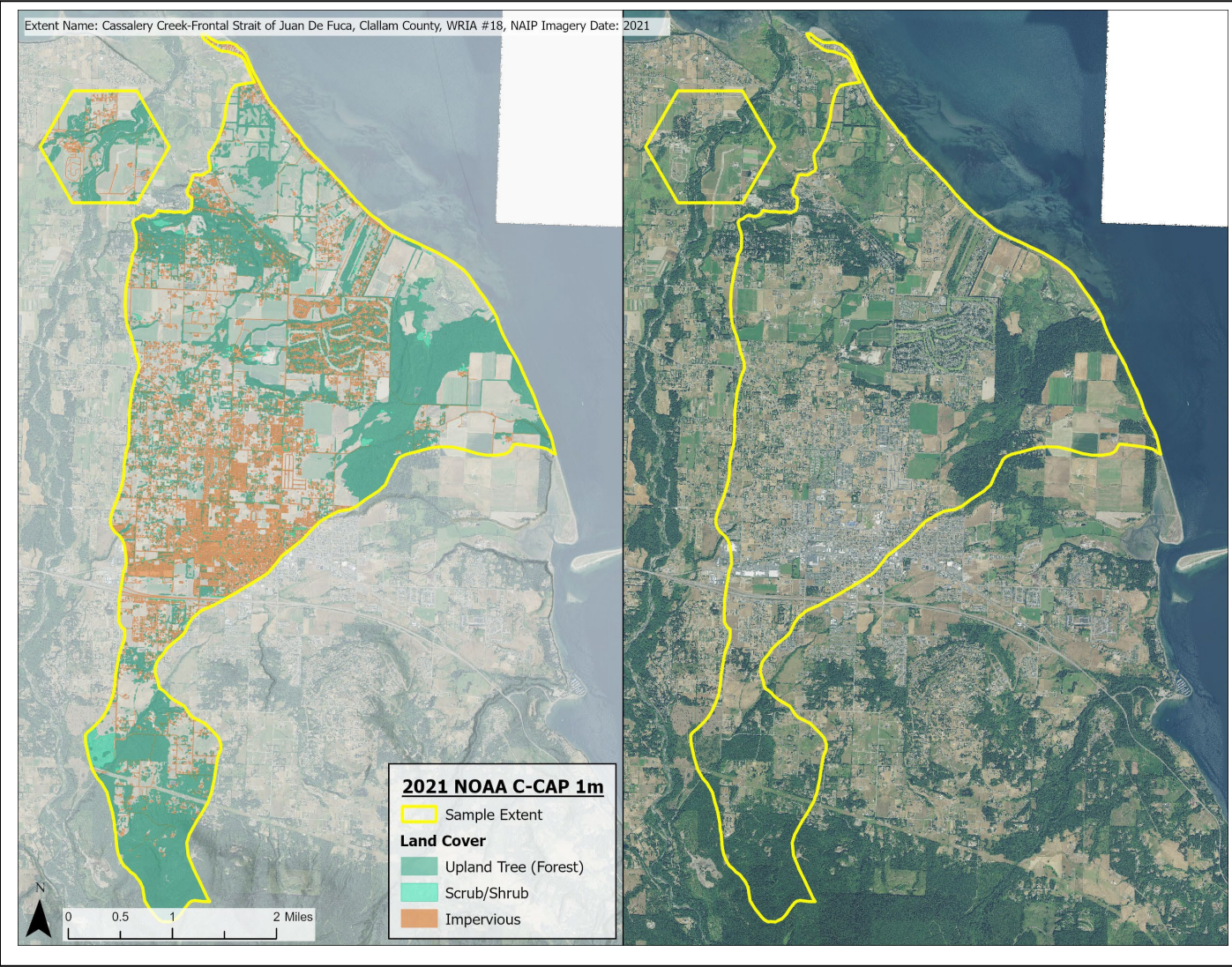
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Appendix A

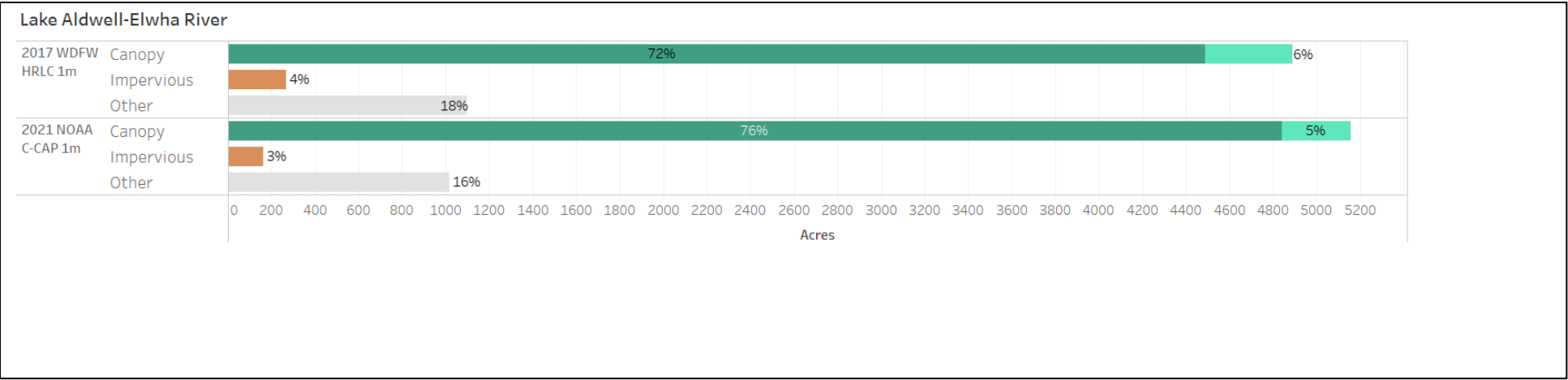
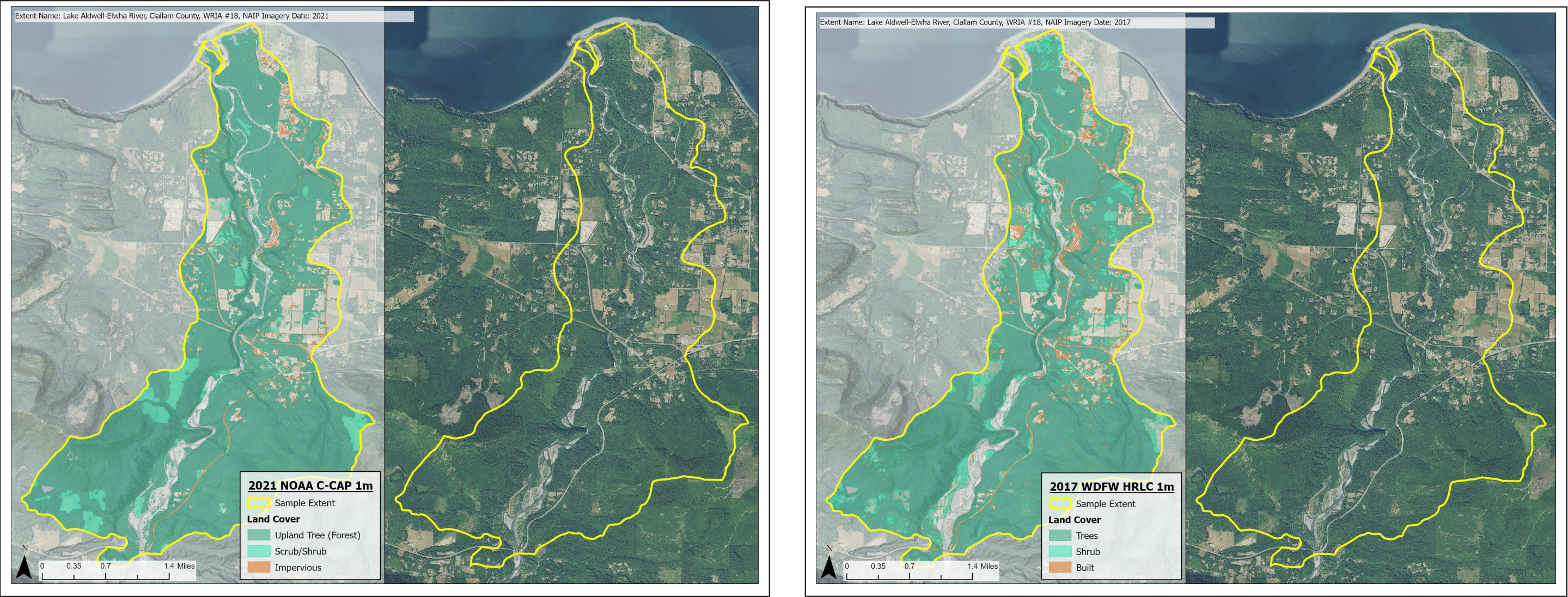
Results

Clallam County – Cassalery Creek-Frontal Strait of Juan De Fuca



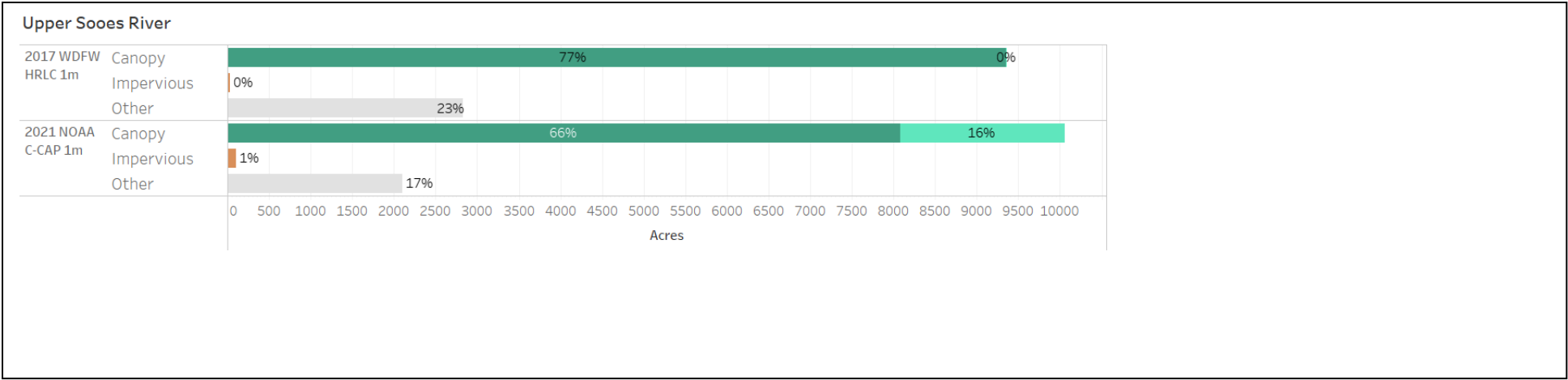
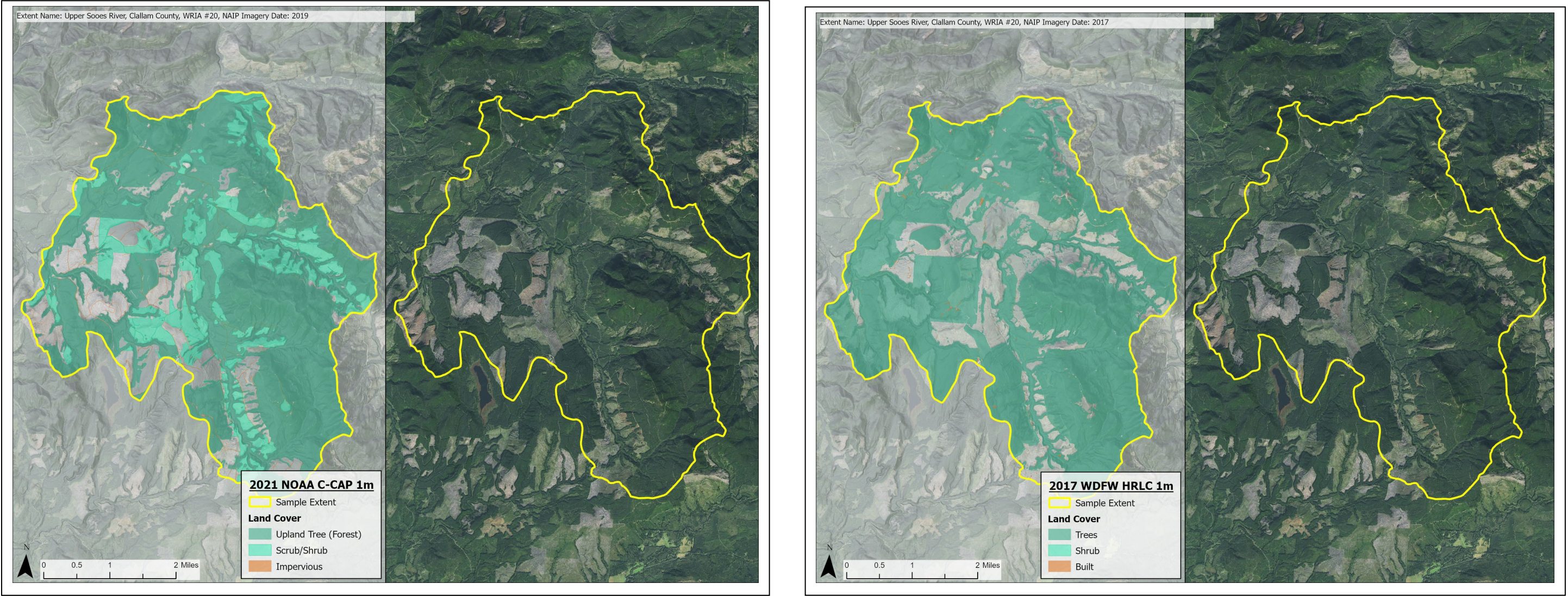
General Observations: This location shows 30% of the extent mapped as Upland Tree (Forest) and 1% Scrub/Shrub for 2021 NOAA C-CAP 1m vs 23% of the extent mapped as Trees and 8% as Shrub for the 2017 WDFW HRLC. Similarly, 15% of the extent is mapped as Impervious for NOAA C-CAP while 21% of the extent is mapped as Built for WDFW HRLC.

Clallam County – Lake Aldwell Elwha River



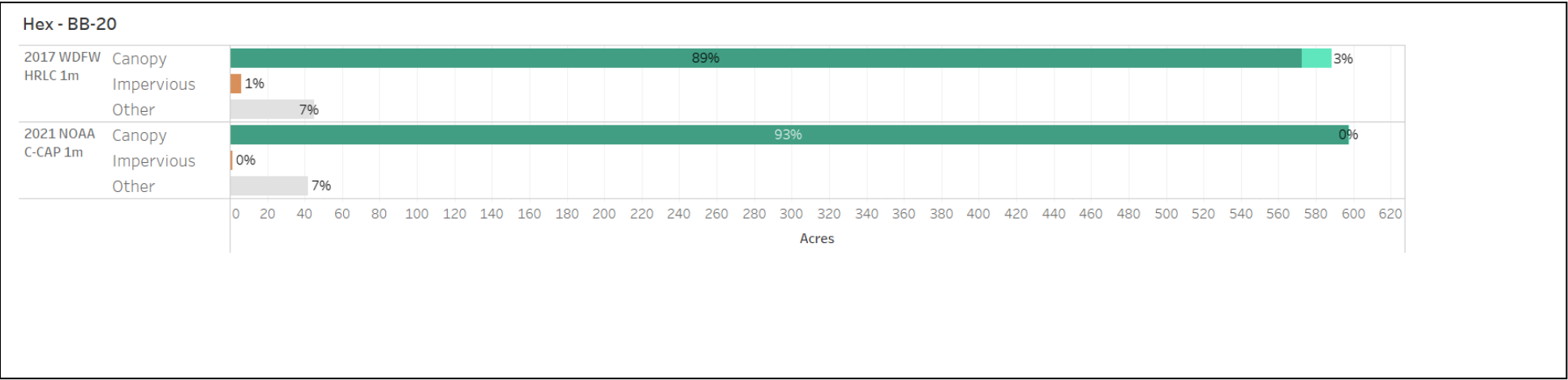
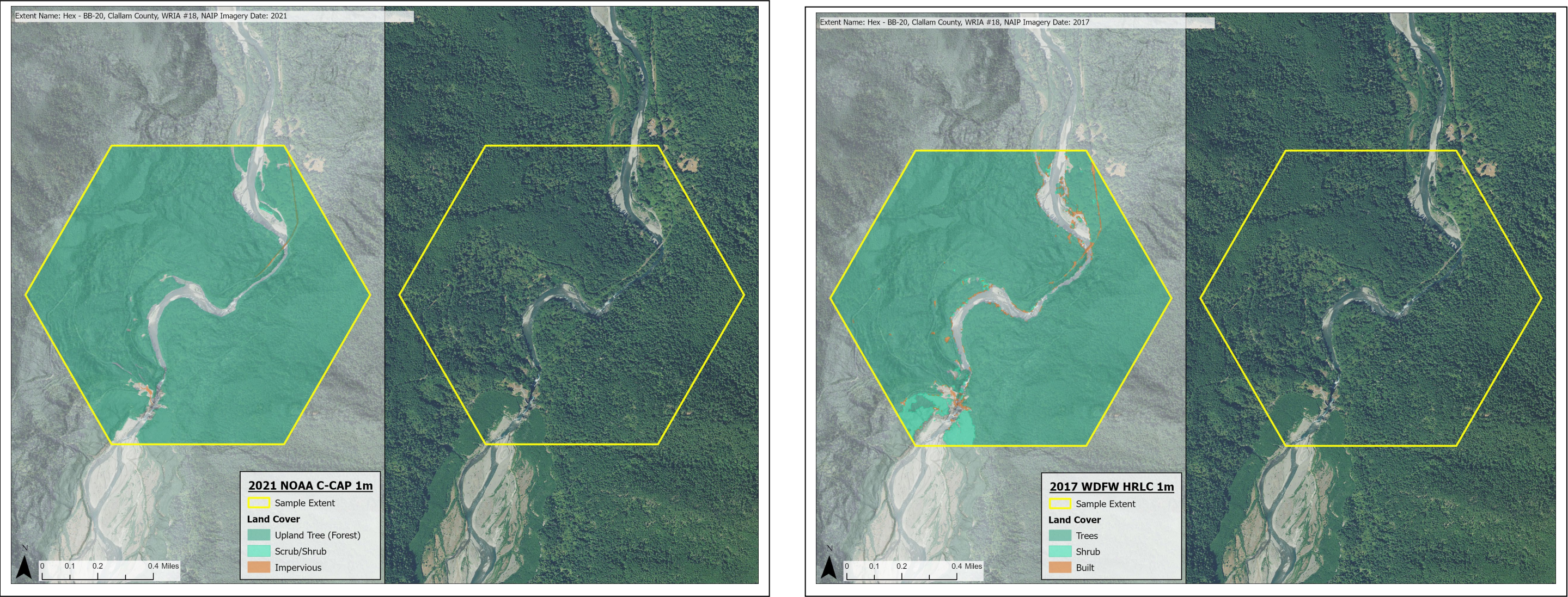
General Observations: This location shows 76% of the extent mapped as Upland Tree (Forest) and 5% Scrub/Shrub for 2021 NOAA C-CAP 1m vs 72% of the extent mapped as Trees and 6% Shrub for the 2017 WDFW HRLC. Similarly, 3% of the extent is mapped as Impervious for NOAA C-CAP while 4% of the extent is mapped as Built for WDFW HRLC.

Clallam County – Upper Sooes River



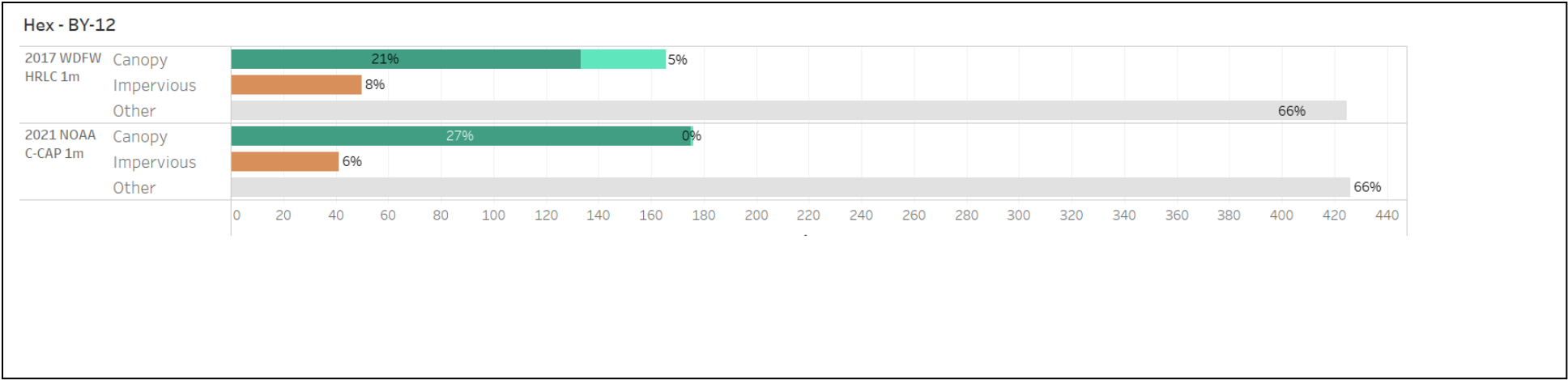
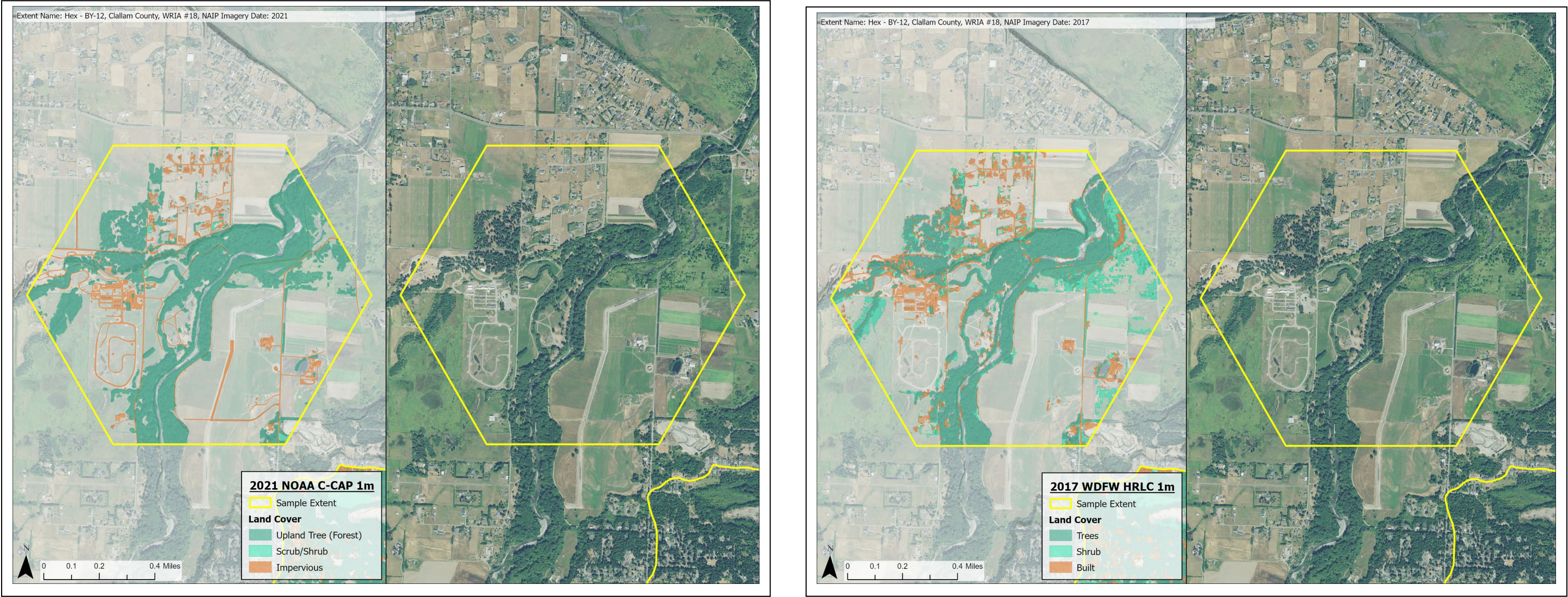
General Observations: This location shows 77% of the extent mapped as Upland Trees (Forest) and 0% Scrub/Shrub for 2021 NOAA C-CAP 1m vs 66% of the extent mapped as Trees and 16% Shrub for the 2017 WDFW HRLC. Similarly, 1% of the extent is mapped as Impervious for NOAA C-CAP while 0 % of the extent is mapped as Built for WDFW HRLC.

Clallam County – Hex – BB-20



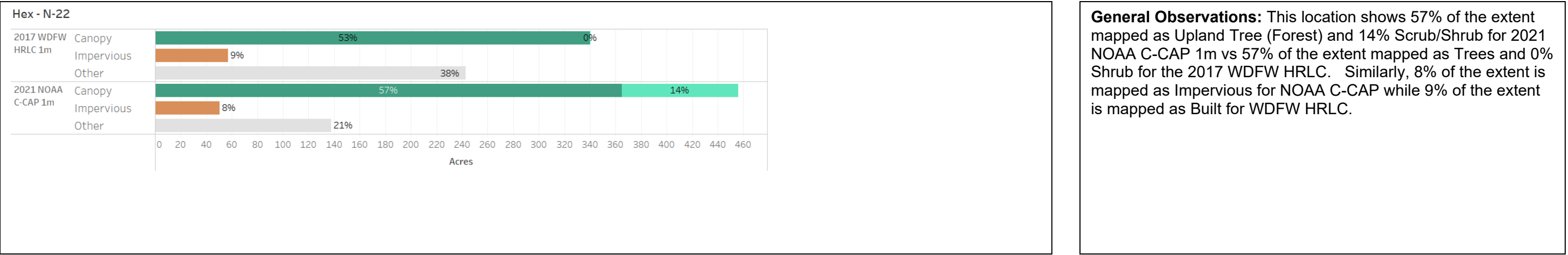
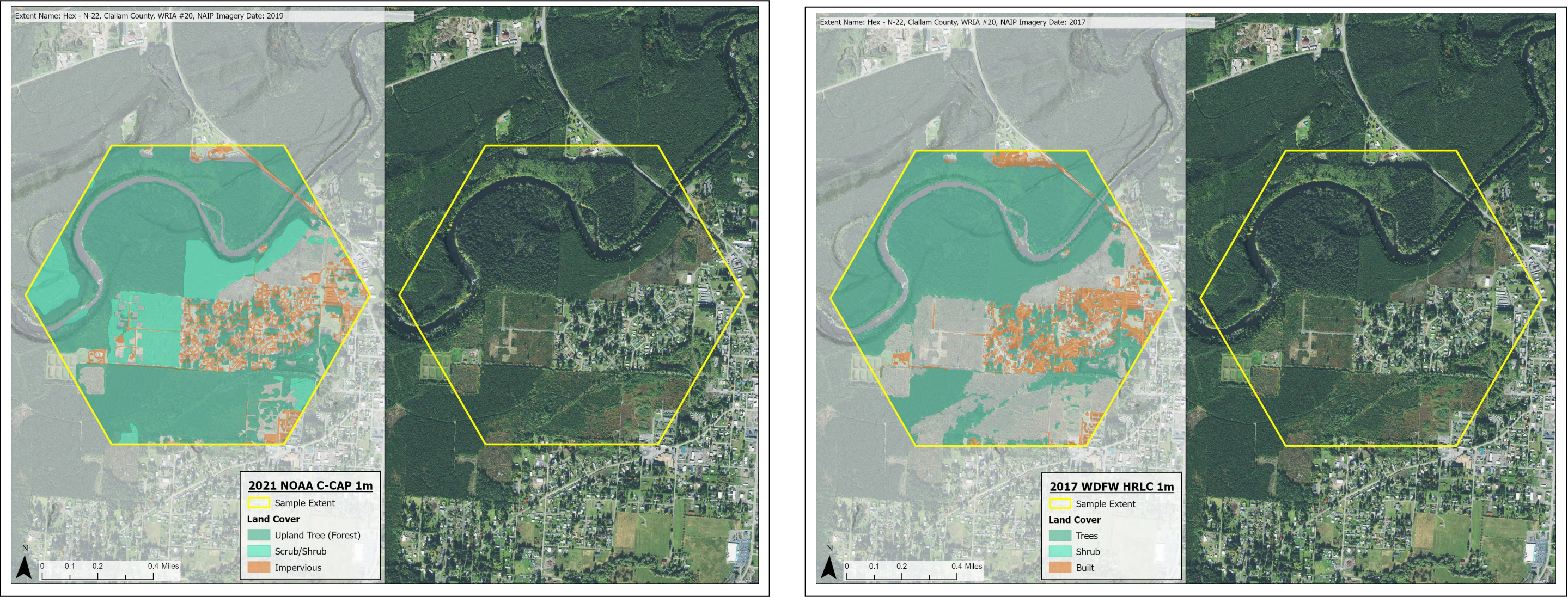
General Observations: This location shows 93% of the extent mapped as Upland Tree (Forest) and 0% Scrub/Shrub for 2021 NOAA C-CAP 1m vs 89% of the extent mapped as Trees and 3% Shrub for the 2017 WDFW HRLC. Similarly, 0% of the extent is mapped as Impervious for NOAA C-CAP while 1% of the extent is mapped as Built for WDFW HRLC.

Clallam County – Hex – BY-12

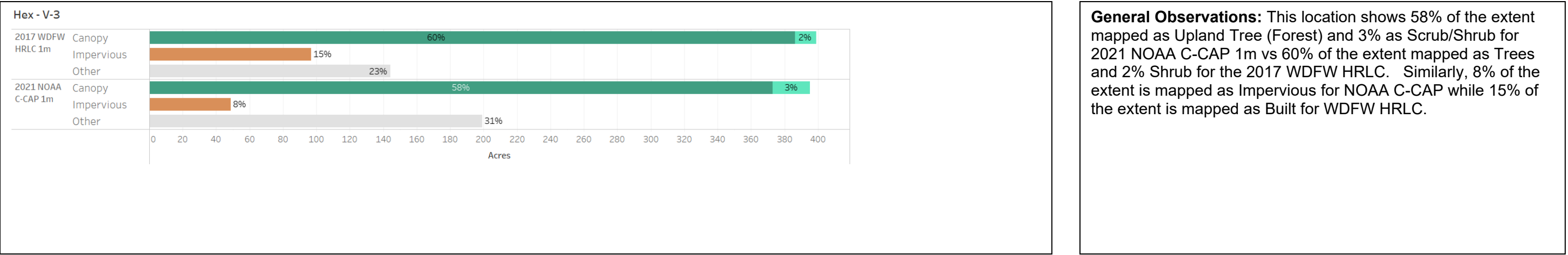
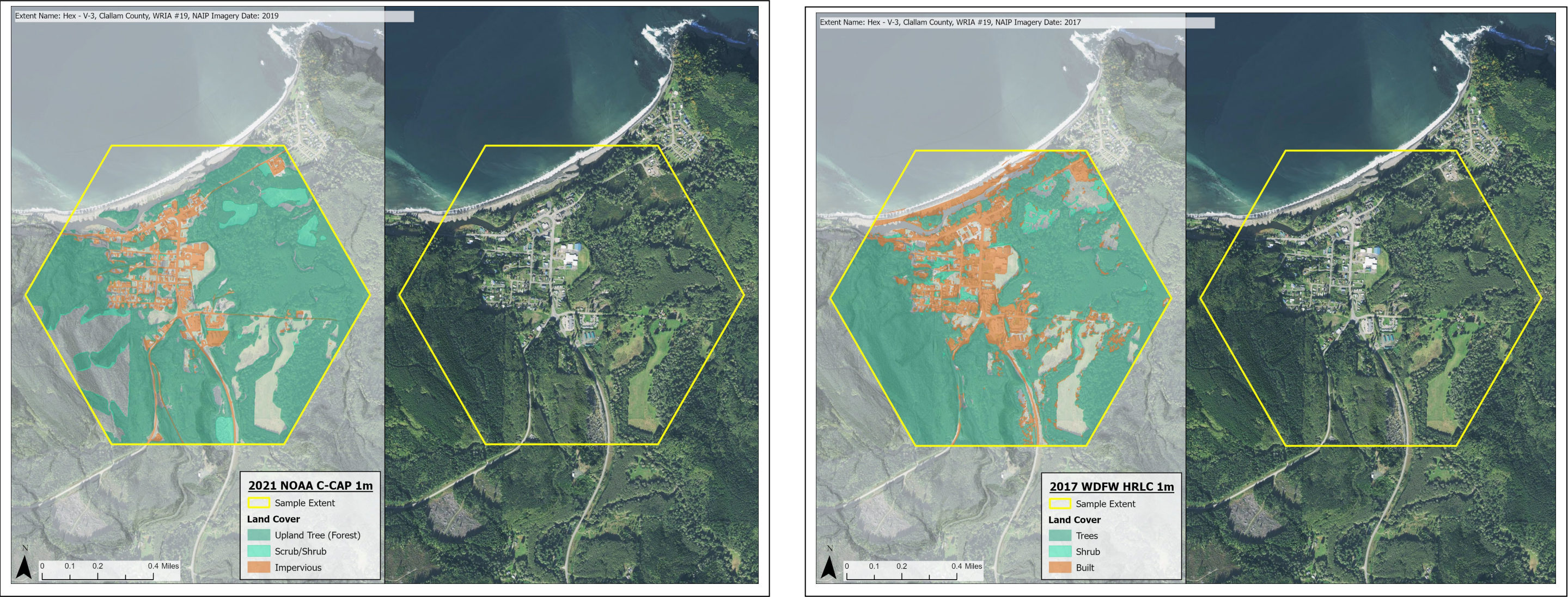


General Observations: This location shows 27% of the extent mapped as Upland Tree (Forest) and 0% Scrub/Shrub for 2021 NOAA C-CAP 1m vs 21% of the extent mapped as Trees and 5% Shrub for the 2017 WDFW HRLC. Similarly, 6% of the extent is mapped as Impervious for NOAA C-CAP while 8% of the extent is mapped as Built for WDFW HRLC.

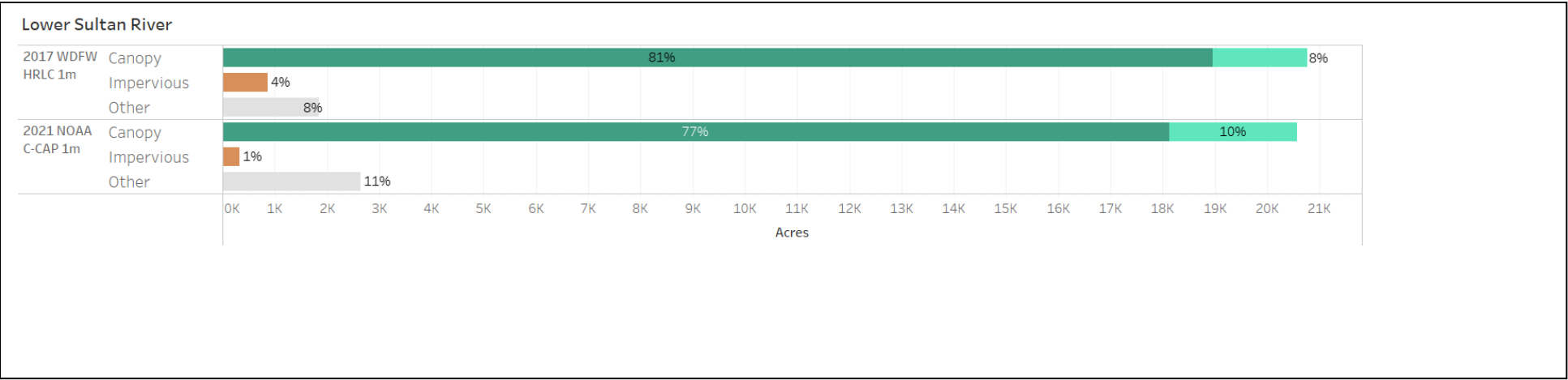
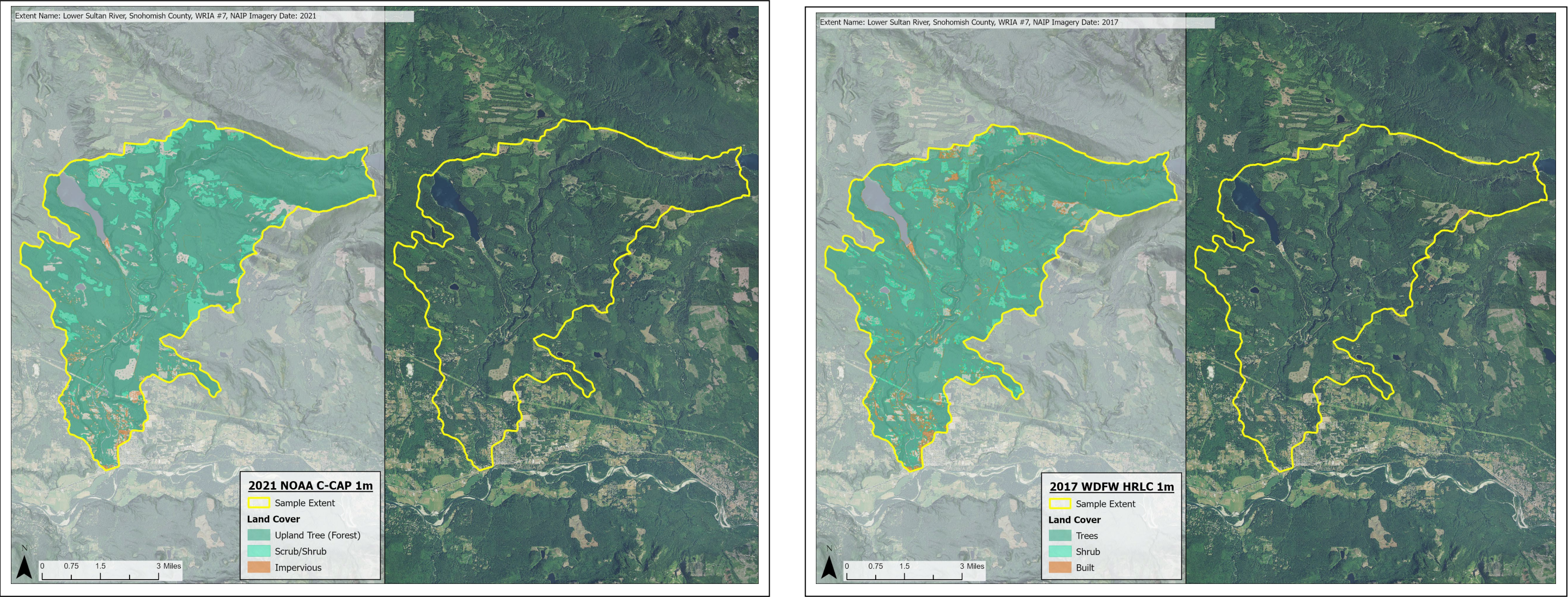
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Clallam County – Hex – V-3

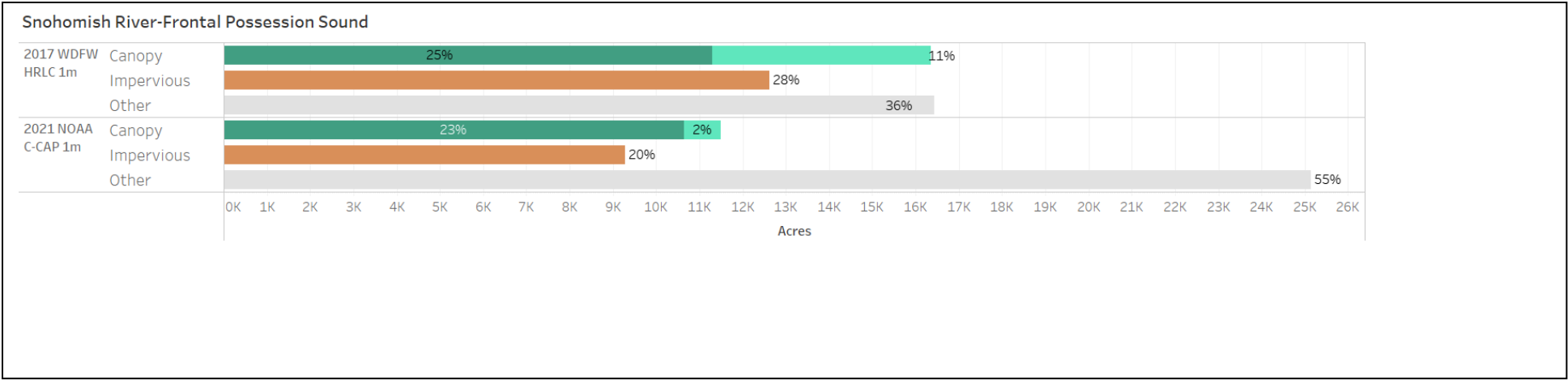
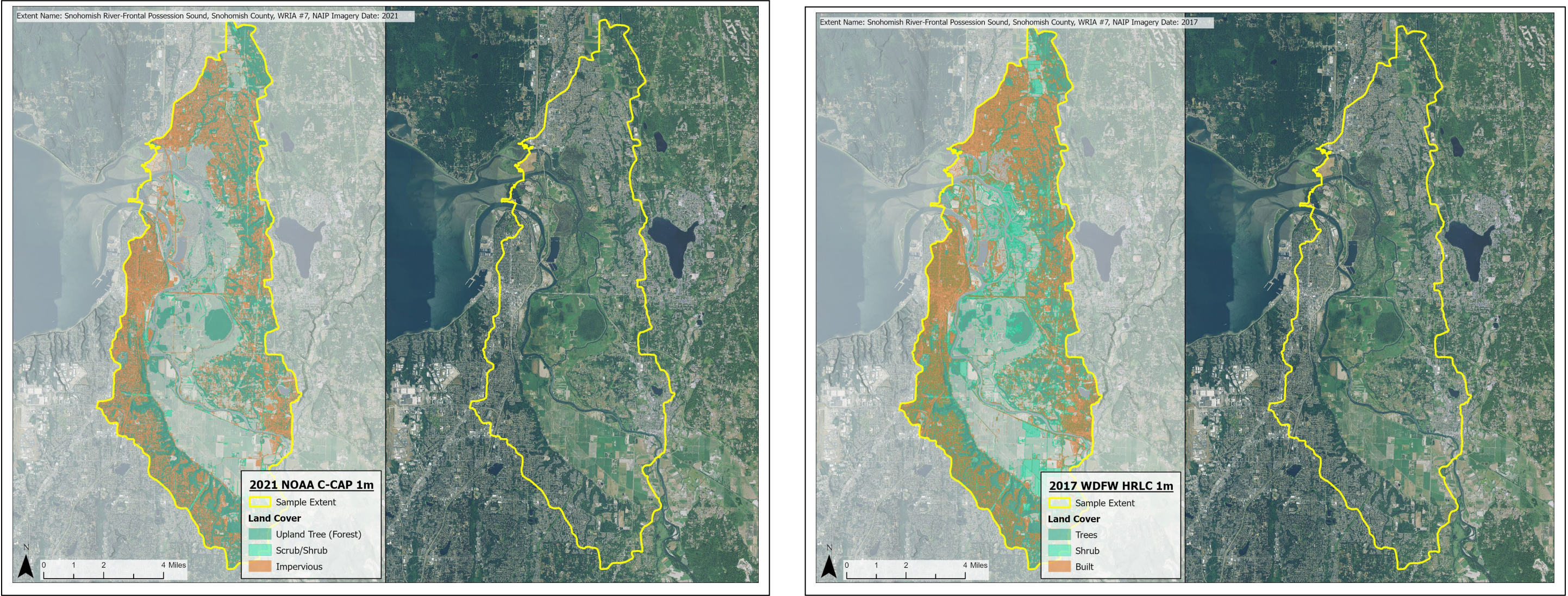


Snohomish County – Lower Sultan River



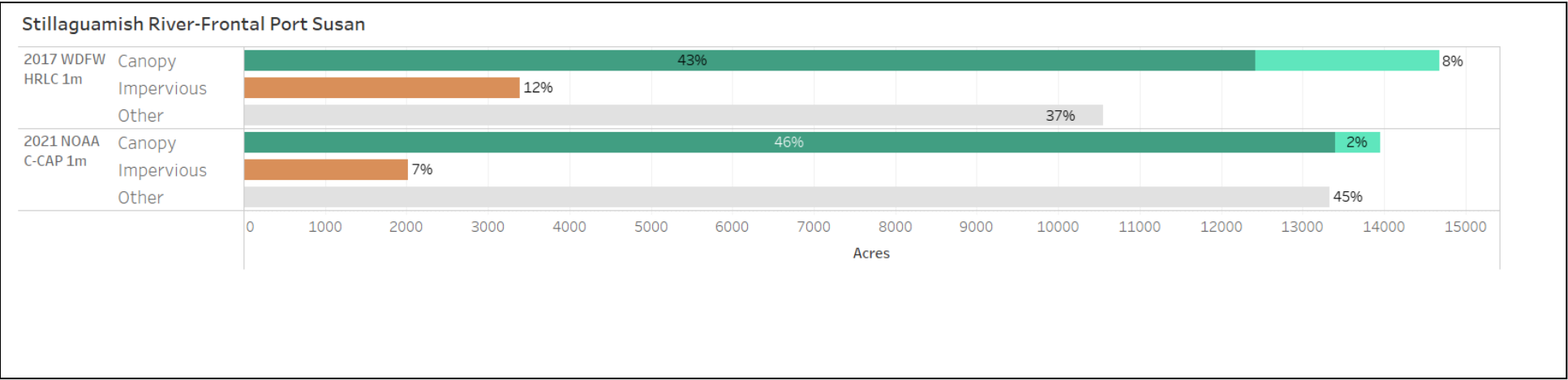
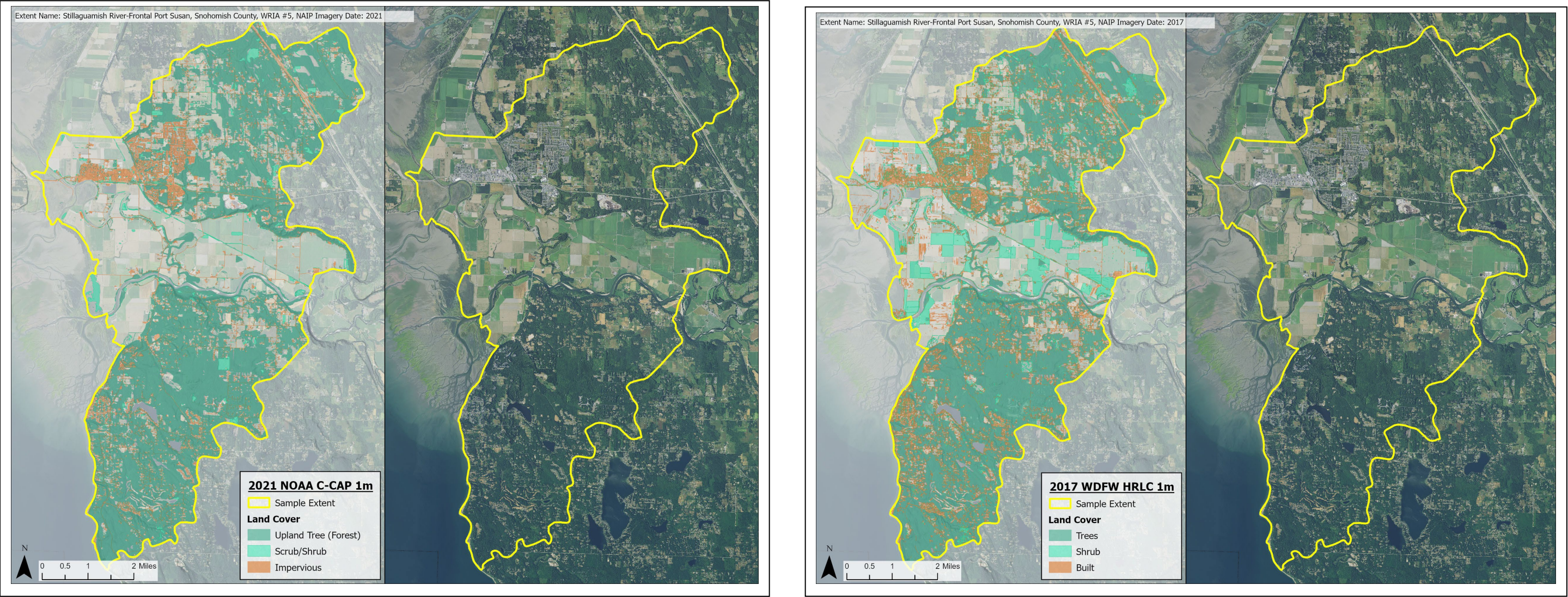
General Observations: This location shows 77% of the extent mapped as Upland Tree (Forest) and 10% Scrub/Shrub for 2021 NOAA C-CAP 1m vs 81% of the extent mapped as Trees and 8% Shrub for the 2017 WDFW HRLC. Similarly, 1% of the extent is mapped as Impervious for NOAA C-CAP while 4% of the extent is mapped as Built for WDFW HRLC.

Snohomish County - Snohomish River – Frontal Possession Sound



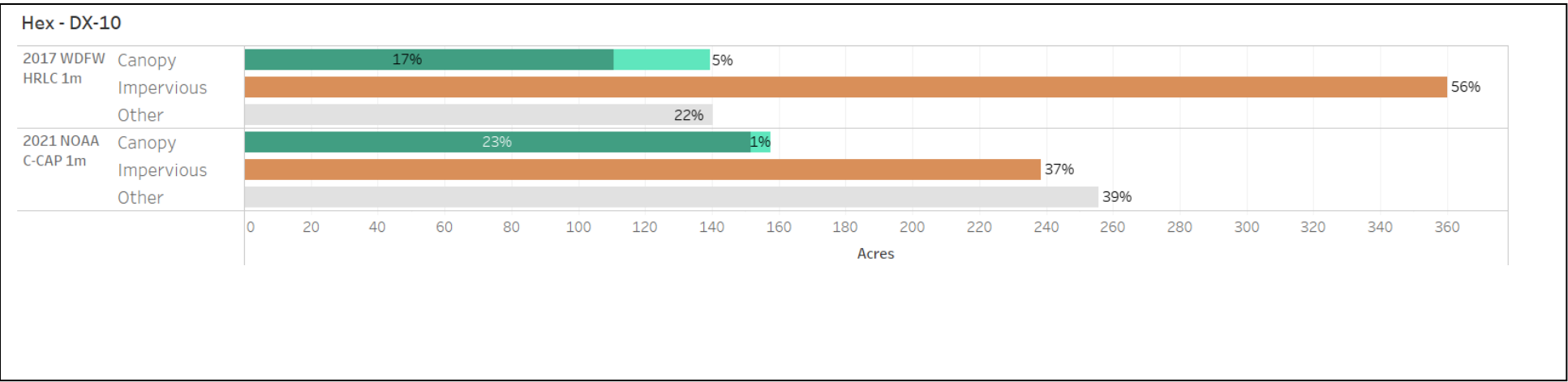
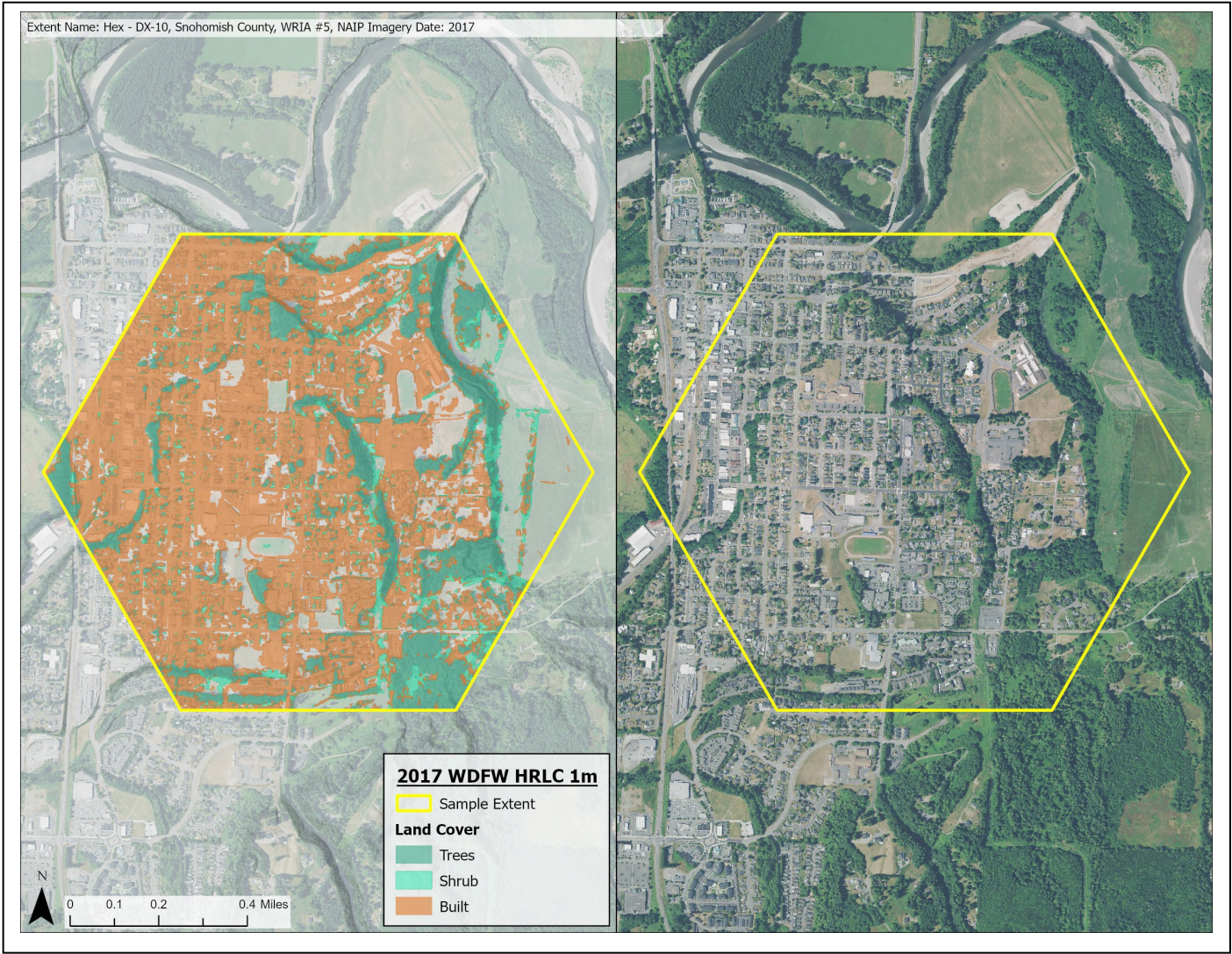
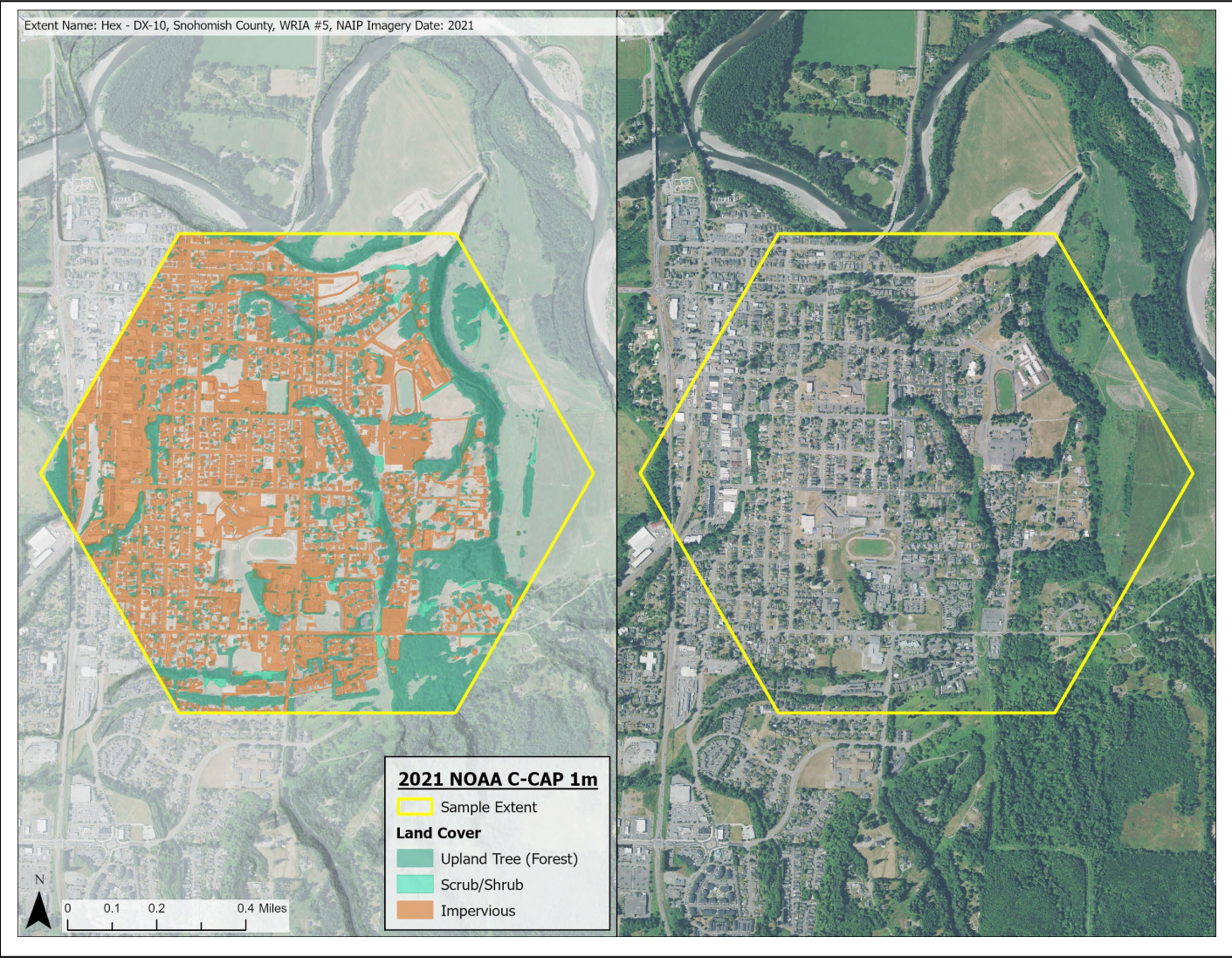
General Observations: This location shows 23% of the extent mapped as Upland Tree (Forest) and 2% as Scrub/Shrub for 2021 NOAA C-CAP 1m vs 25% of the extent mapped as Trees and 11% Shrub for the 2017 WDFW HRLC. Similarly, 20 % of the extent is mapped as Impervious for NOAA C-CAP while 28% of the extent is mapped as Built for WDFW HRLC.

Snohomish County – Stillaguamish River – Frontal Port Susan



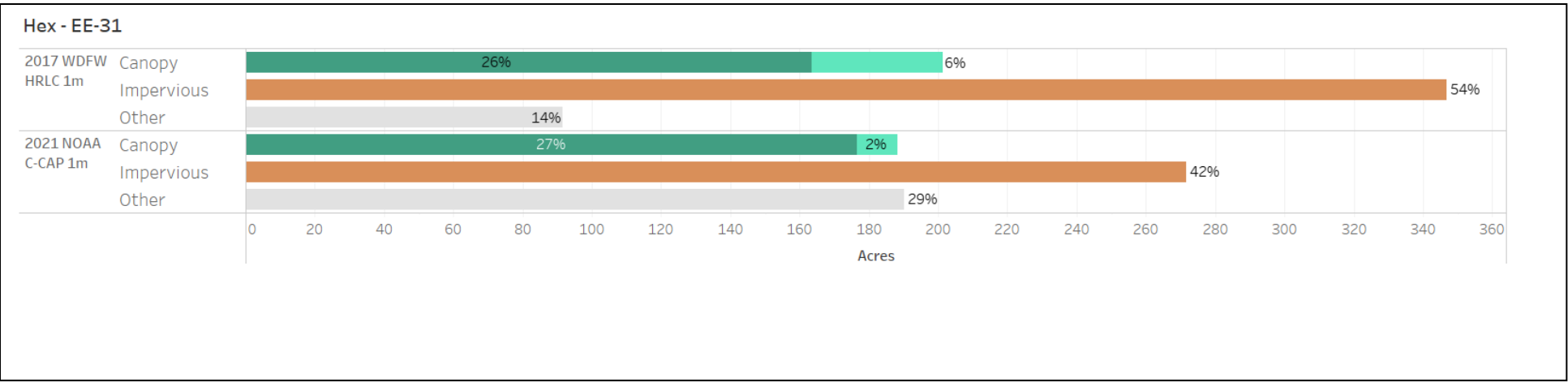
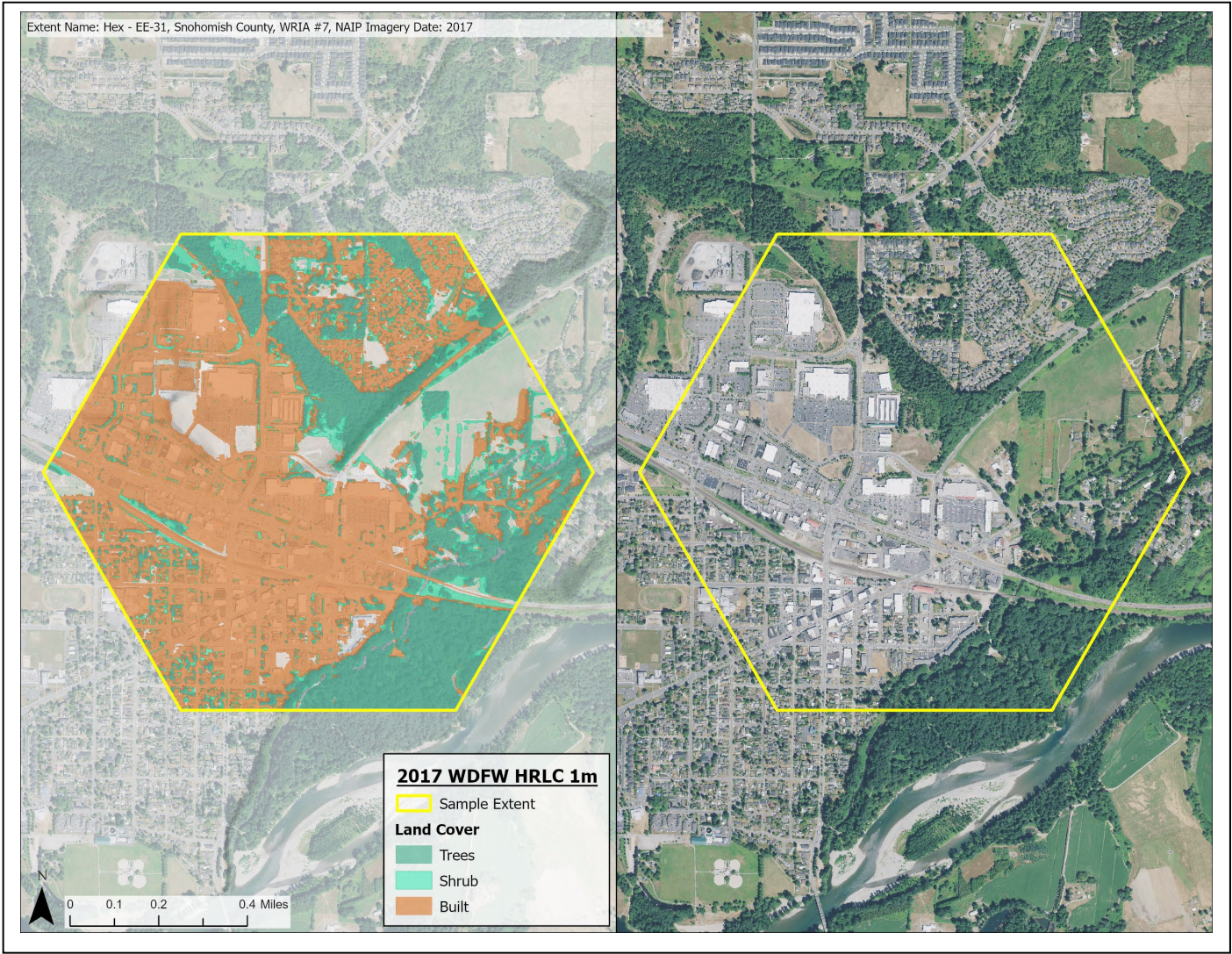
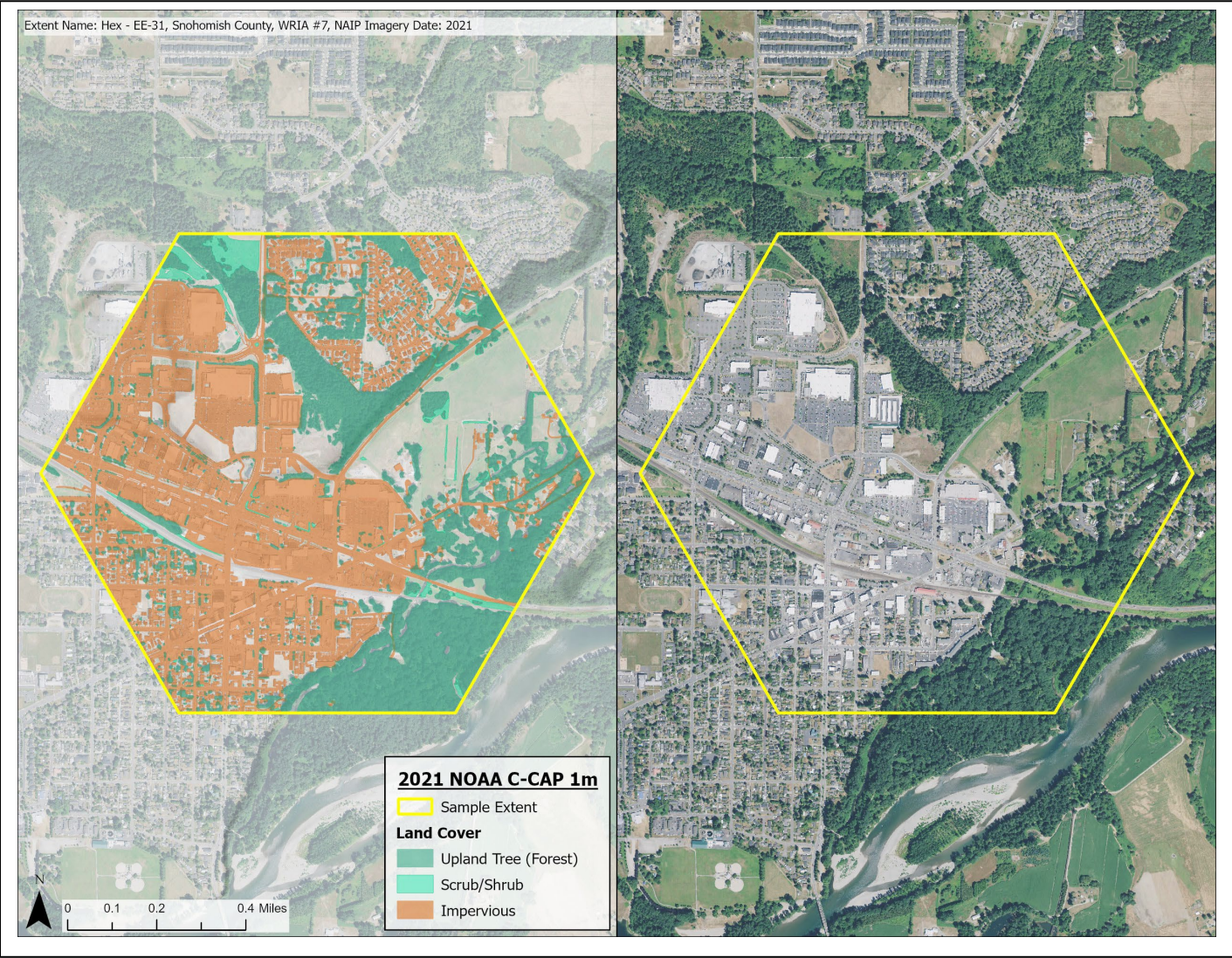
General Observations: This location shows 46% of the extent mapped as Upland Tree (Forest) and 2% Scrub/Shrub for 2021 NOAA C-CAP 1m vs 43% of the extent mapped as Trees and 8% Shrub for the 2017 WDFW HRLC. Similarly, 7% of the extent is mapped as Impervious for NOAA C-CAP while 12% of the extent is mapped as Built for WDFW HRLC.

Snohomish County – Hex – DX-10



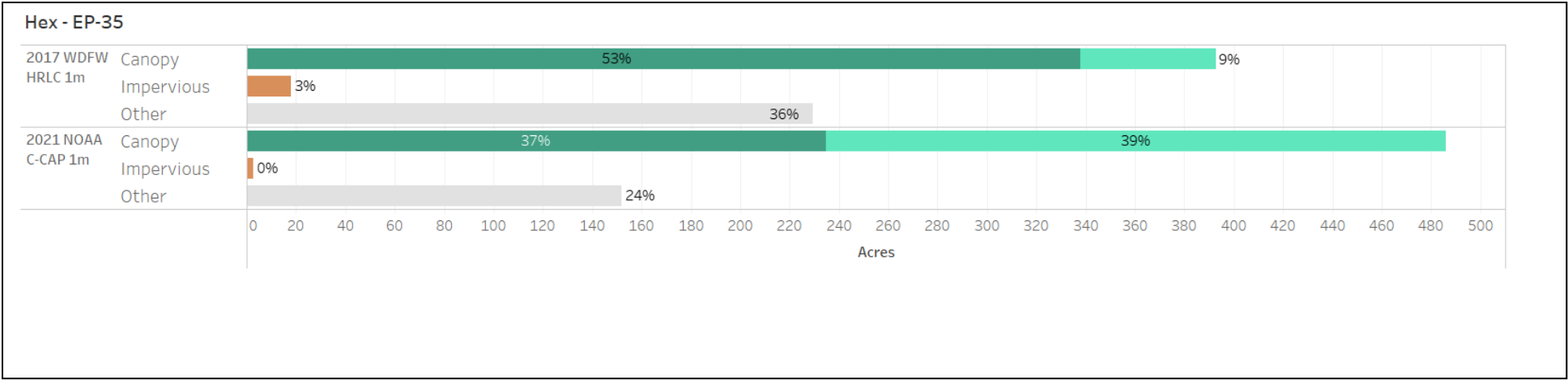
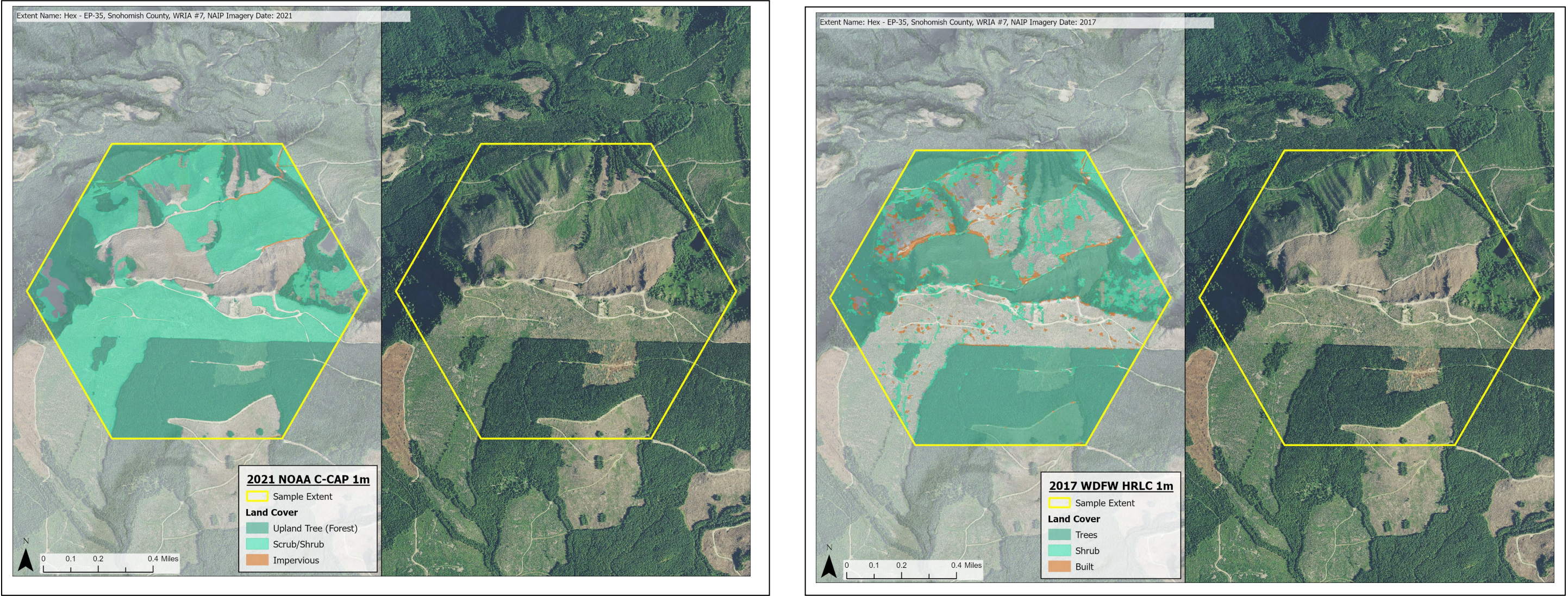
General Observations: This location shows 23% of the extent mapped as Upland Tree (Forest) and 1% as for 2021 NOAA C-CAP 1m vs 17% of the extent mapped as Trees and 5% Shrub for the 2017 WDFW HRLC. Similarly, 37% of the extent is mapped as Impervious for NOAA C-CAP while 56% of the extent is mapped as Built for WDFW HRLC.

Snohomish County – Hex – EE-31



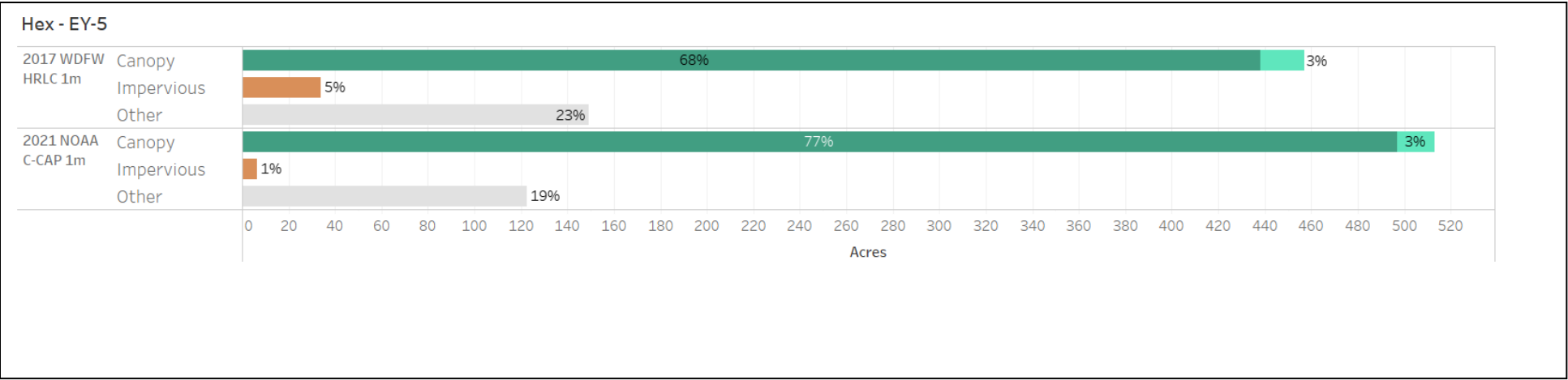
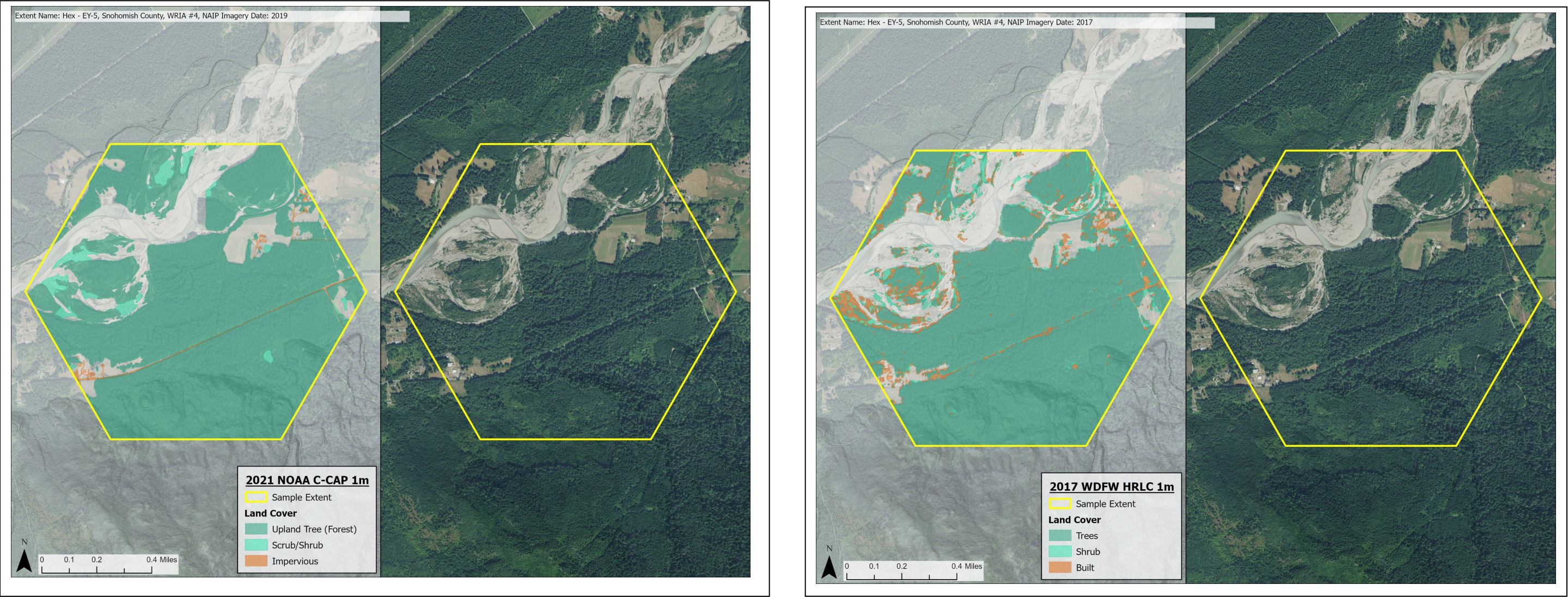
General Observations: This location shows 27% of the extent mapped as Upland Tree (Forest) and 2% Scrub/Shrub for 2021 NOAA C-CAP 1m vs 26% of the extent mapped as Trees and 6% Shrub for the 2017 WDFW HRLC. Similarly, 42% of the extent is mapped as Impervious for NOAA C-CAP while 54% of the extent is mapped as Built for WDFW HRLC.

Snohomish County – EP-35



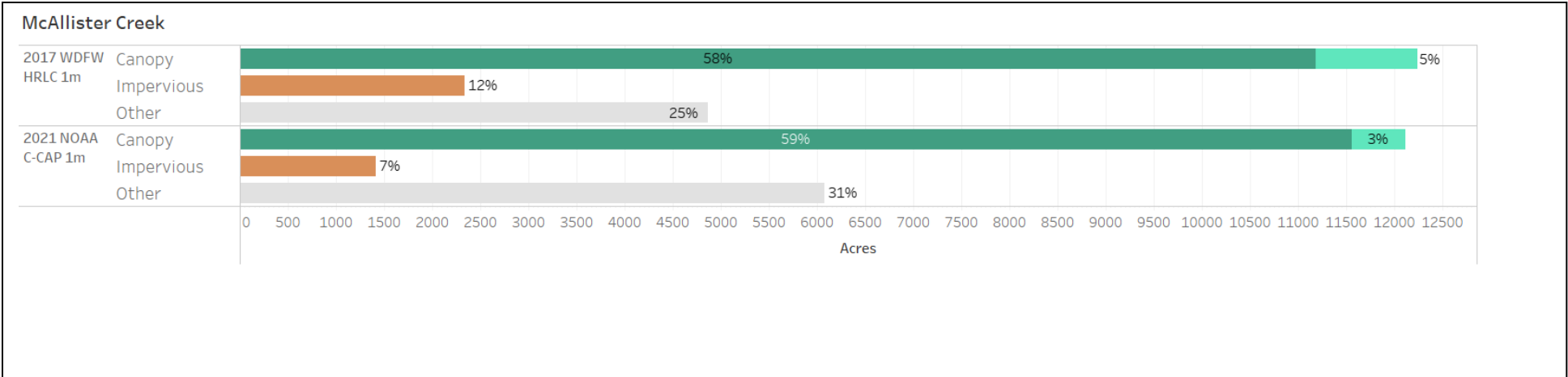
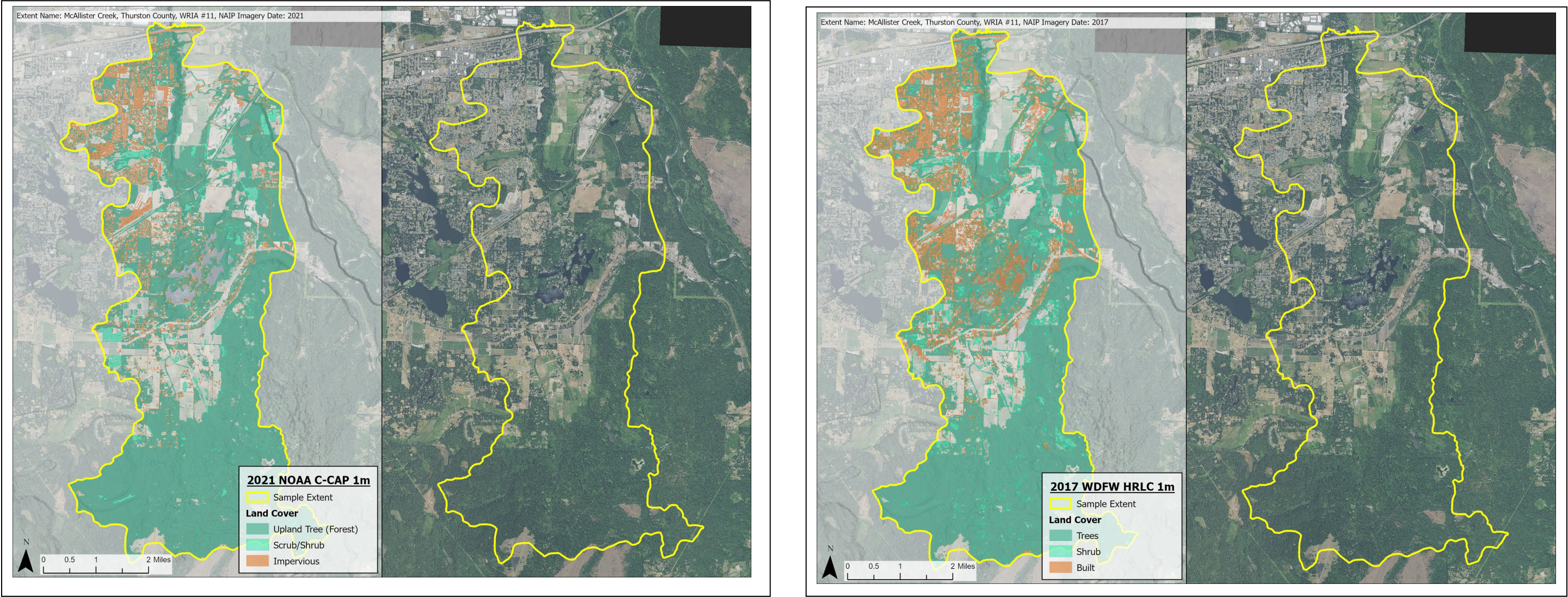
General Observations: This location shows 37% of the extent mapped as Upland Tree (Forest) and 39% Scrub/Shrub for 2021 NOAA C-CAP 1m vs 53% of the extent mapped as Trees and 9% Shrub for the 2017 WDFW HRLC. Similarly, <1% of the extent is mapped as Impervious for NOAA C-CAP while 3% of the extent is mapped as Built for WDFW HRLC. The significant difference in the presence of shrub in this location for the 2021 NOAA C-CAP 1m can be attributed to shrub growth in a recently logged timber stand between 2017 and 2021. Similarly, it is likely there were more trees present in this location in 2017 and thus represented in the percent tree canopy for WDFW HRLC 1m.

Snohomish County – EY-5



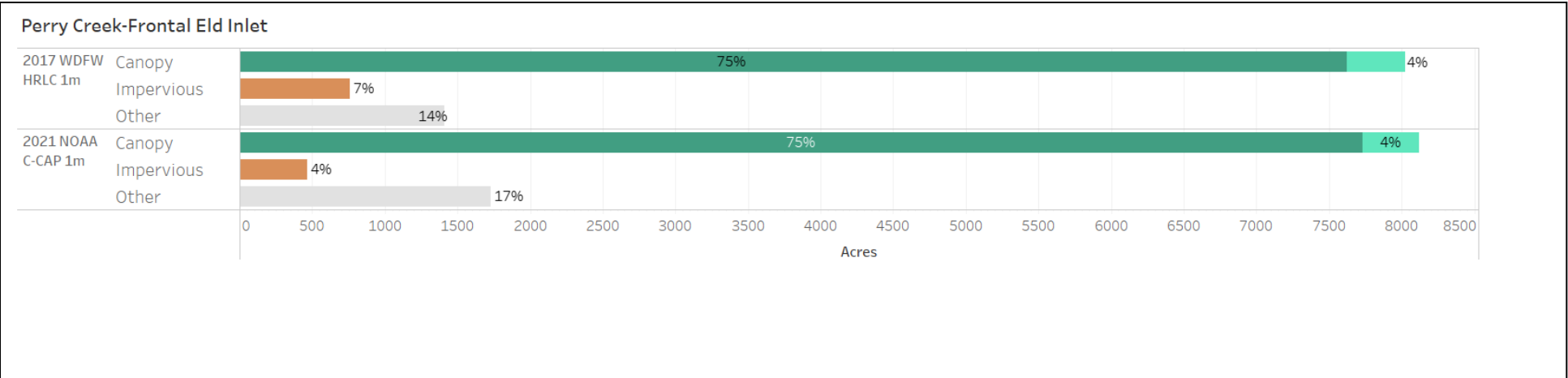
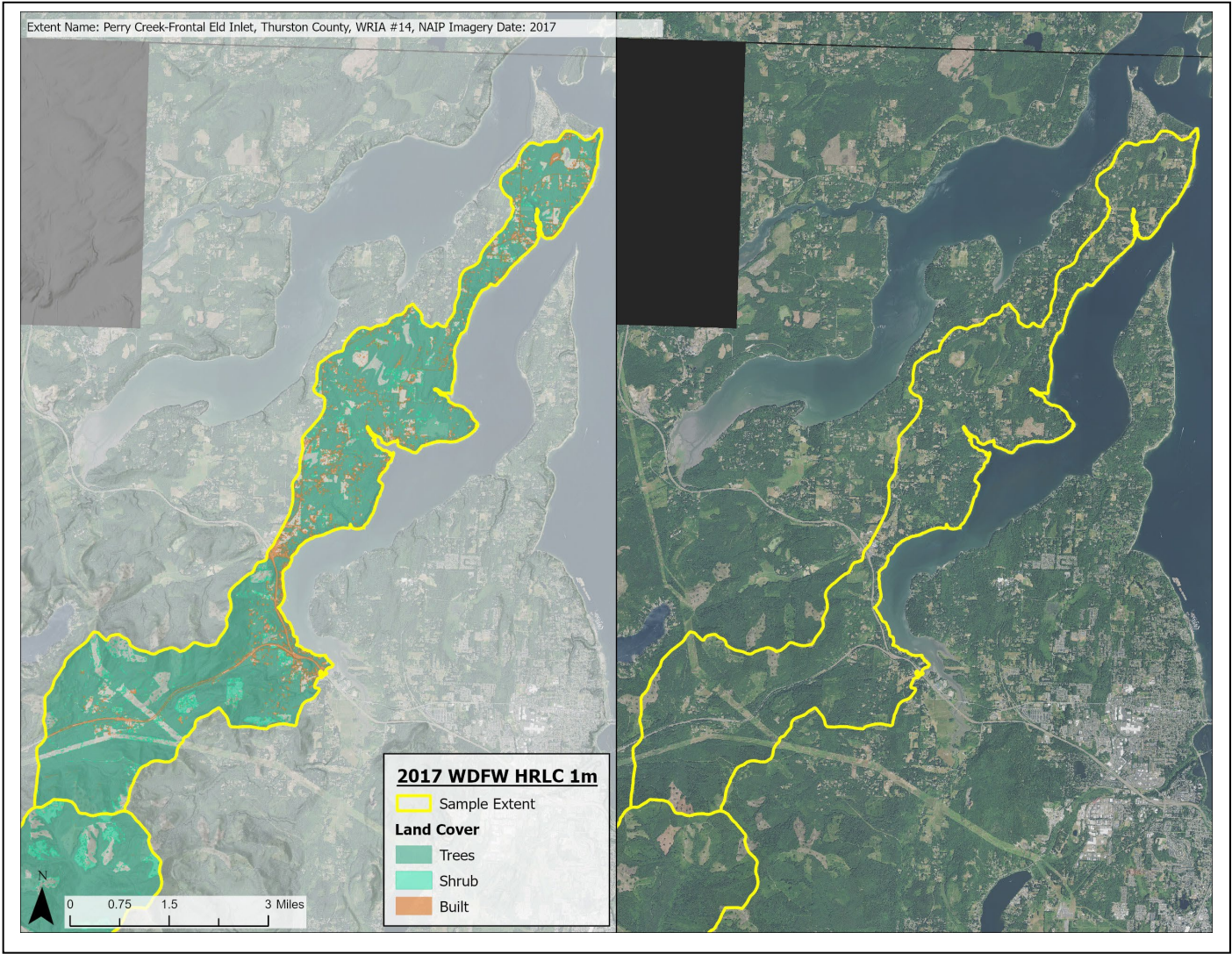
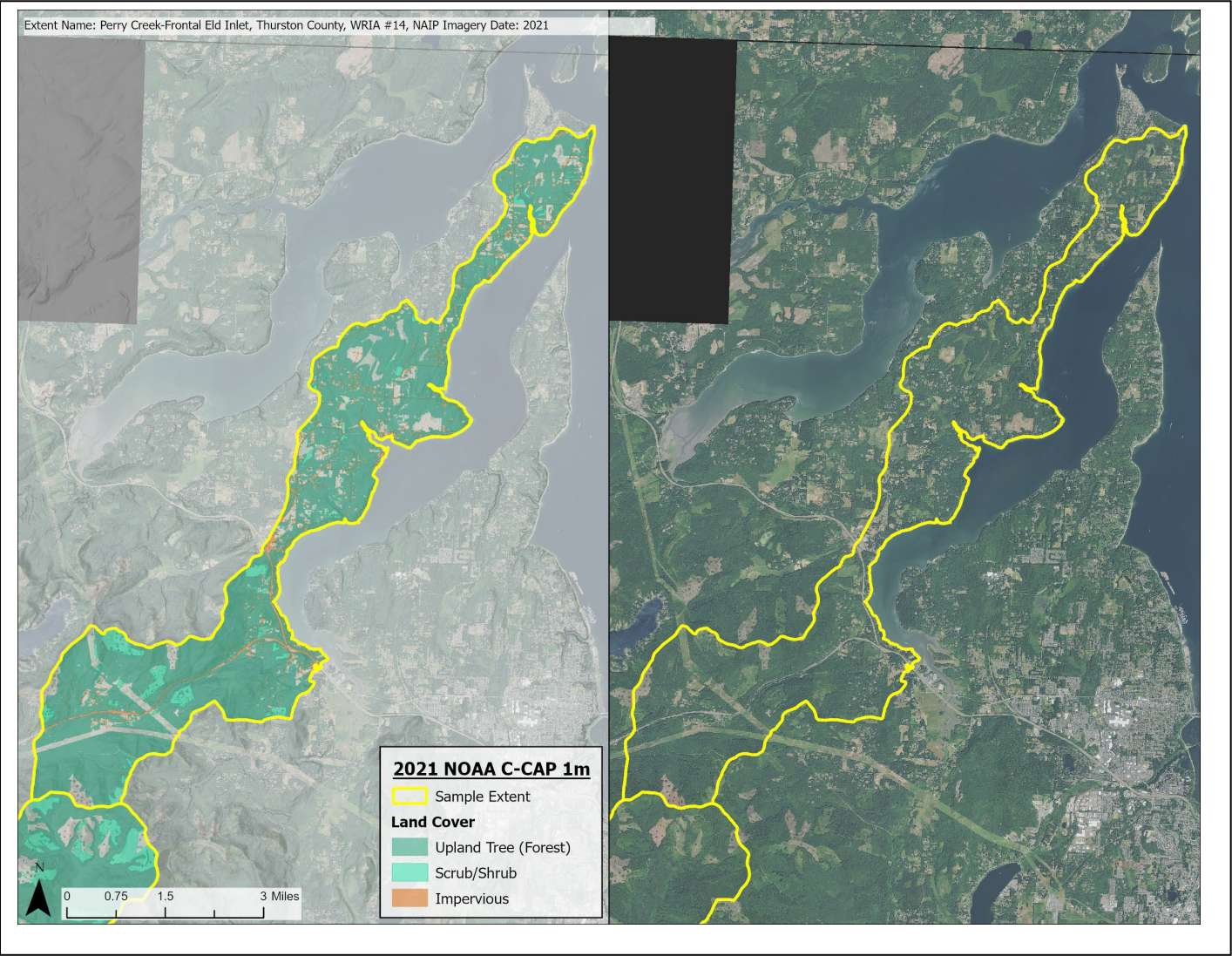
General Observations: This location shows 77% of the extent mapped as Upland Tree (Forest) and 3% Scrub/Shrub for 2021 NOAA C-CAP 1m vs 68% of the extent mapped as Trees and 3% Shrub for the 2017 WDFW HRLC. Similarly, 1% of the extent is mapped as Impervious for NOAA C-CAP while 5% of the extent is mapped as Built for WDFW HRLC.

Thurston County – McAllister Creek



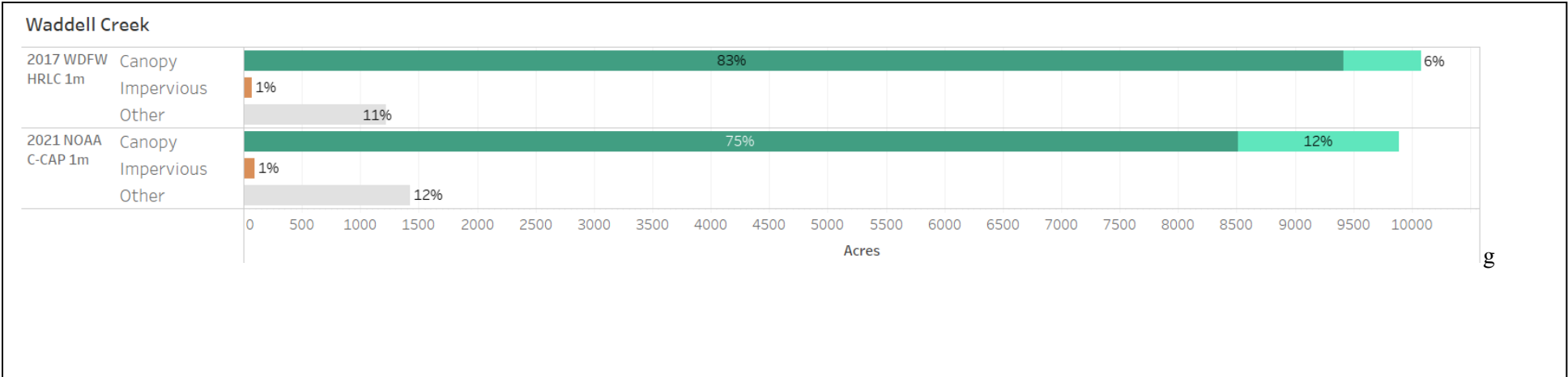
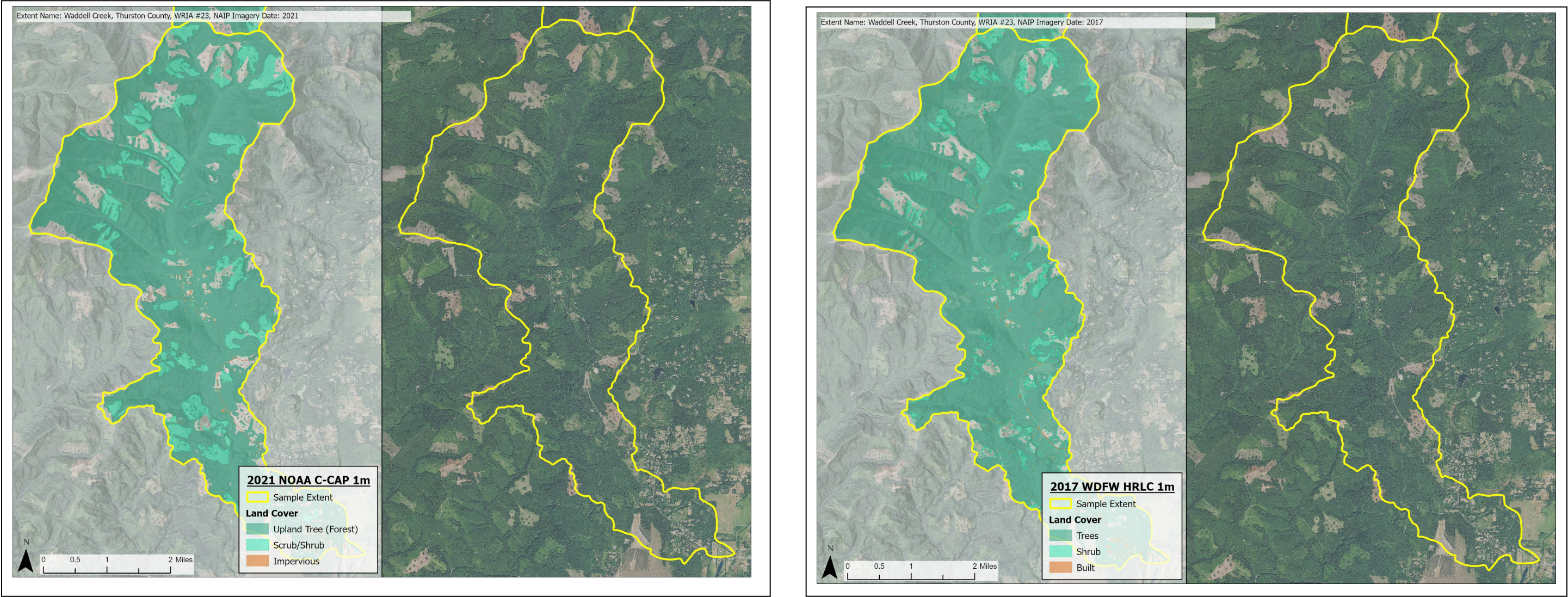
General Observations: This location shows 59% of the extent mapped as Upland Tree (Forest) and 3% for 2021 NOAA C-CAP 1m vs 58% of the extent mapped as Trees and 5% Shrub for the 2017 WDFW HRLC. Similarly, 7% of the extent is mapped as Impervious for NOAA C-CAP while 12% of the extent is mapped as Built for WDFW HRLC.

Thurston County – Perry Creek – Frontal Eld Inlet



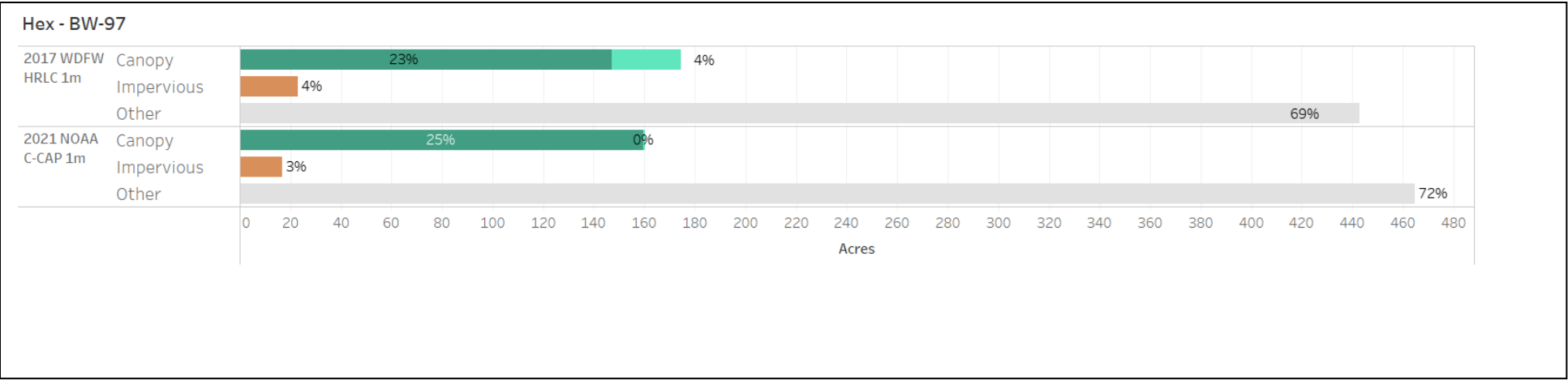
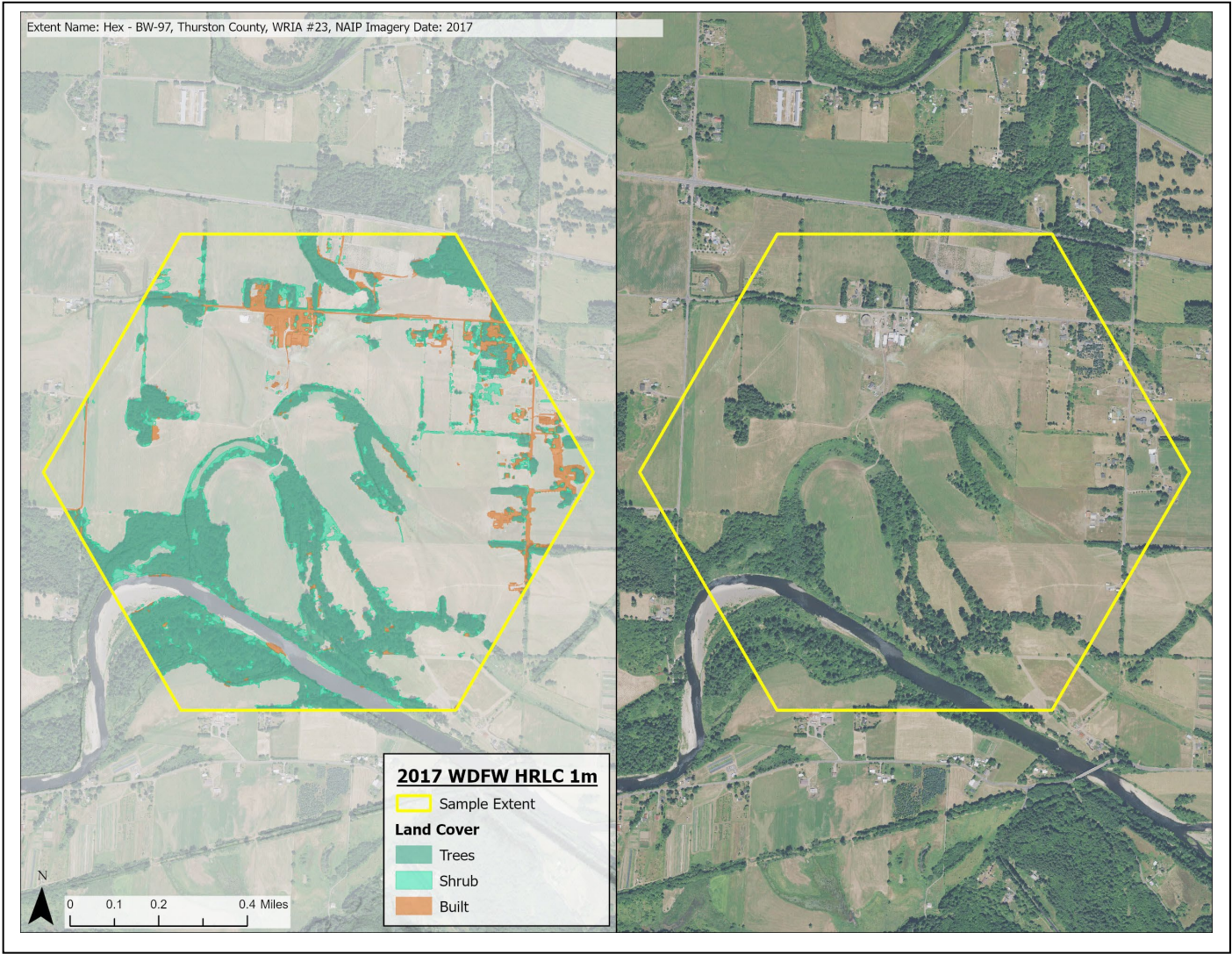
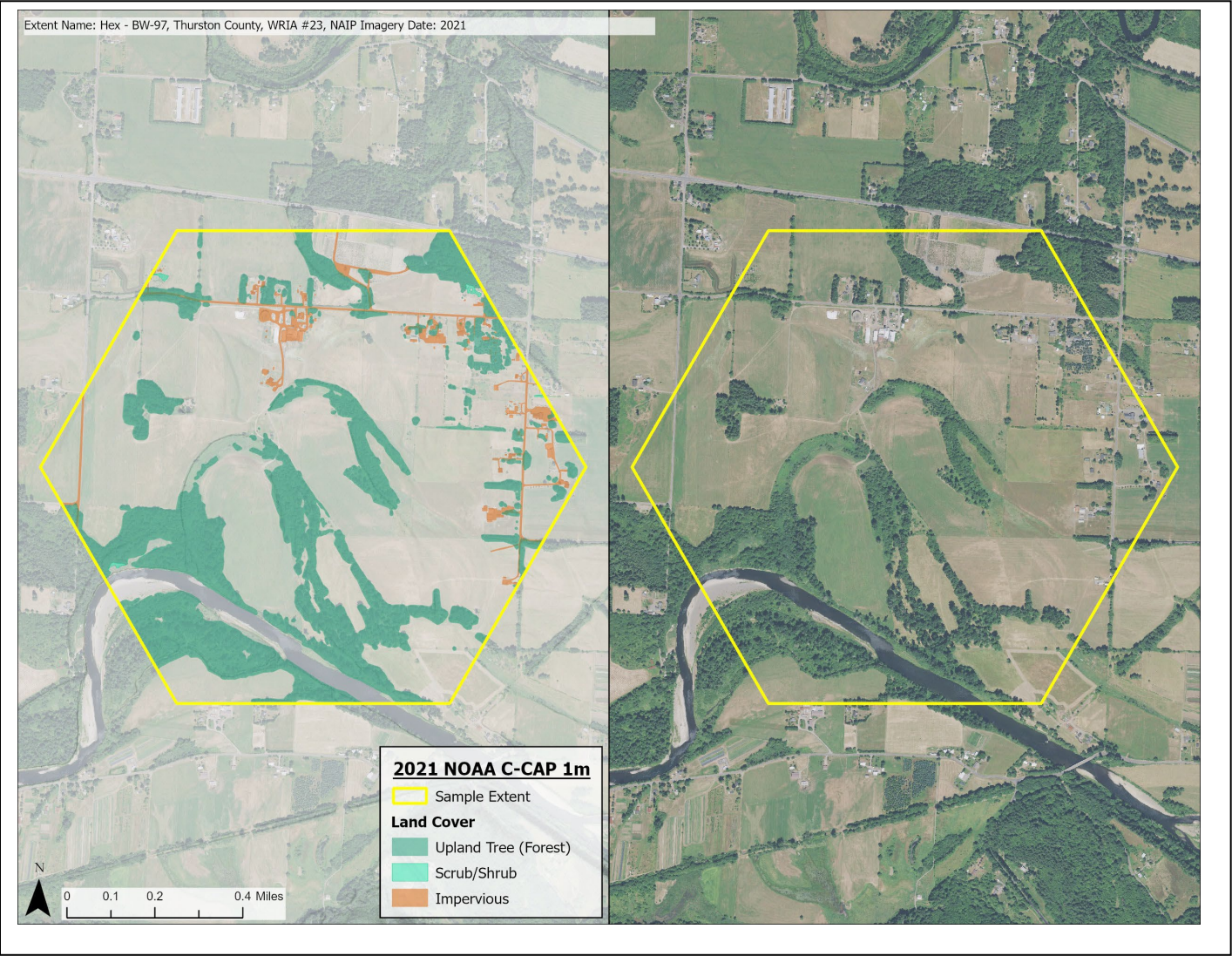
General Observations: This location shows 79% of the extent mapped as Upland Tree (Forest) and 4% Scrub/Shrub for 2021 NOAA C-CAP 1m vs 75% of the extent mapped as Trees and 4% Shrub for the 2017 WDFW HRLC. Similarly, 4% of the extent is mapped as Impervious for NOAA C-CAP while 7% of the extent is mapped as Built for WDFW HRLC.

Thurston County – Waddell Creek



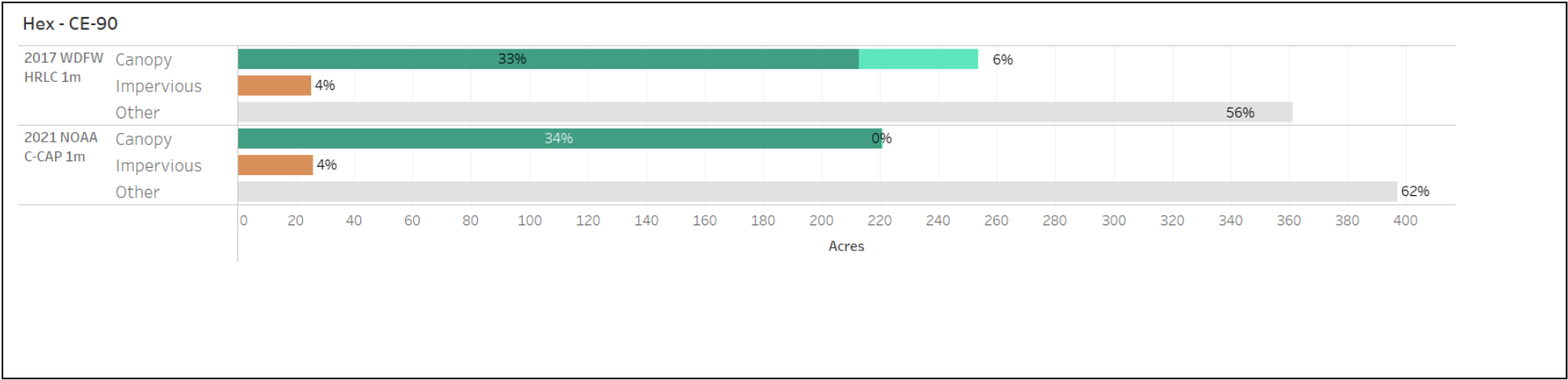
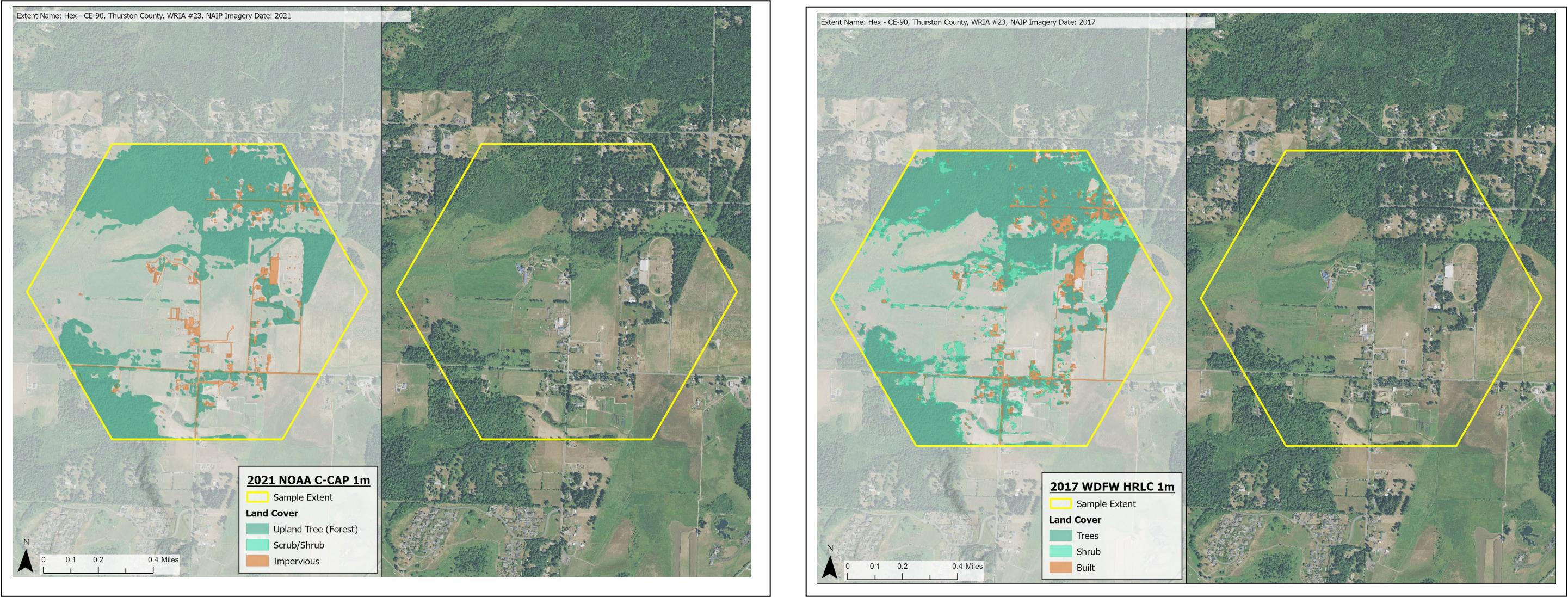
General Observations: This location shows 75% of the extent mapped as Upland Tree (Forest) and 12% Scrub/Shrub for 2021 NOAA C-CAP 1m vs 83% of the extent mapped as Trees and 6% Shrub for the 2017 WDFW HRLC. Similarly, 1% of the extent is mapped as Impervious for NOAA C-CAP while 1% of the extent is mapped as Built for WDFW HRLC. Differences in shrub percent between 2017 (NOAA) and 2021 (WDFW) can likely be attributed to vegetation (shrub) growth following a recent logging activity.

Thurston County – Hex – BW-97



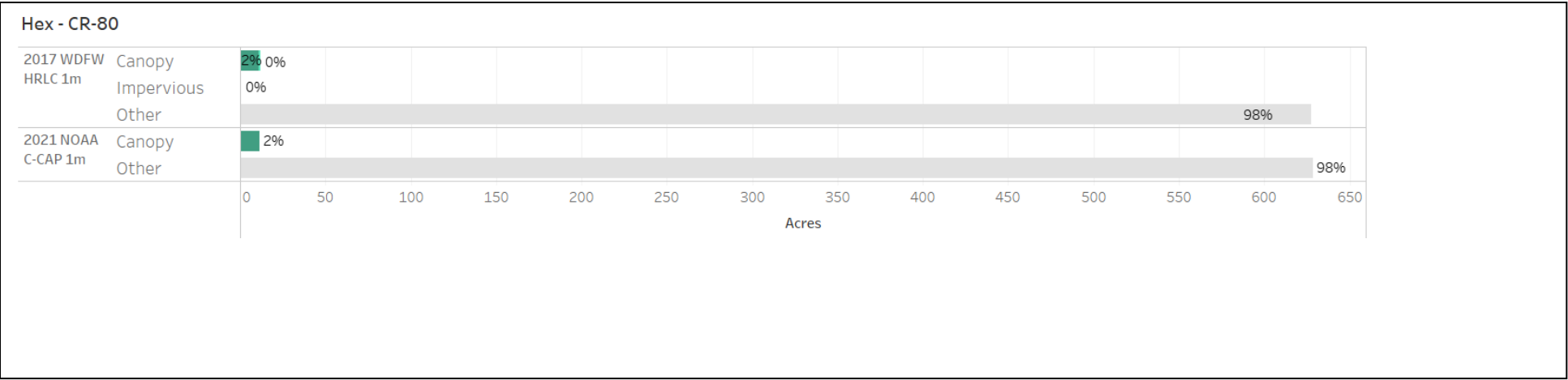
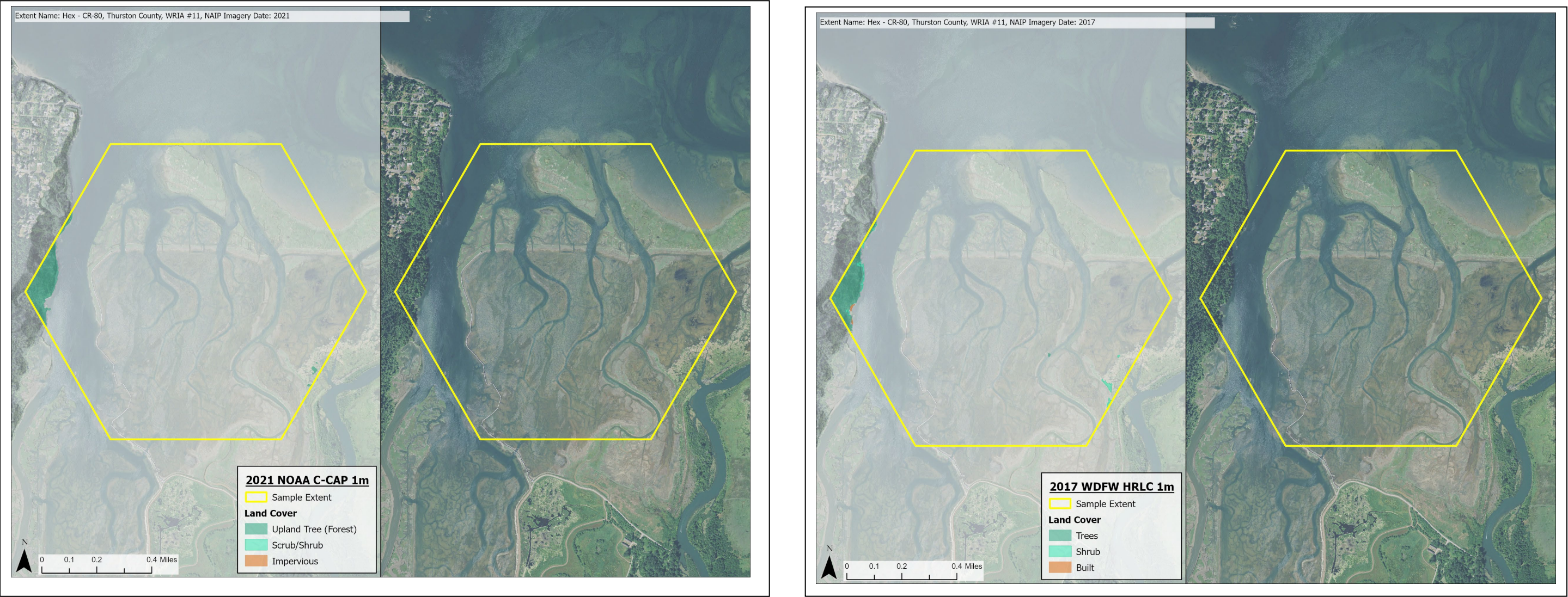
General Observations: This location shows 25% of the extent mapped as Upland Tree (Forest) and 0% as Scrub/Shrub for 2021 NOAA C-CAP 1m vs 23% of the extent mapped as Trees and 4% Shrub for the 2017 WDFW HRLC. Similarly, 3% of the extent is mapped as Impervious for NOAA C-CAP while 4% of the extent is mapped as Built for WDFW HRLC.

Thurston County – Hex – CE-90



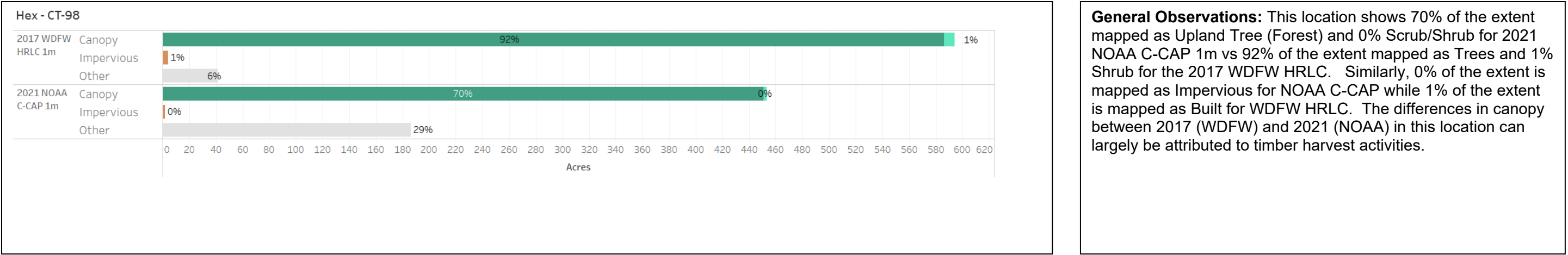
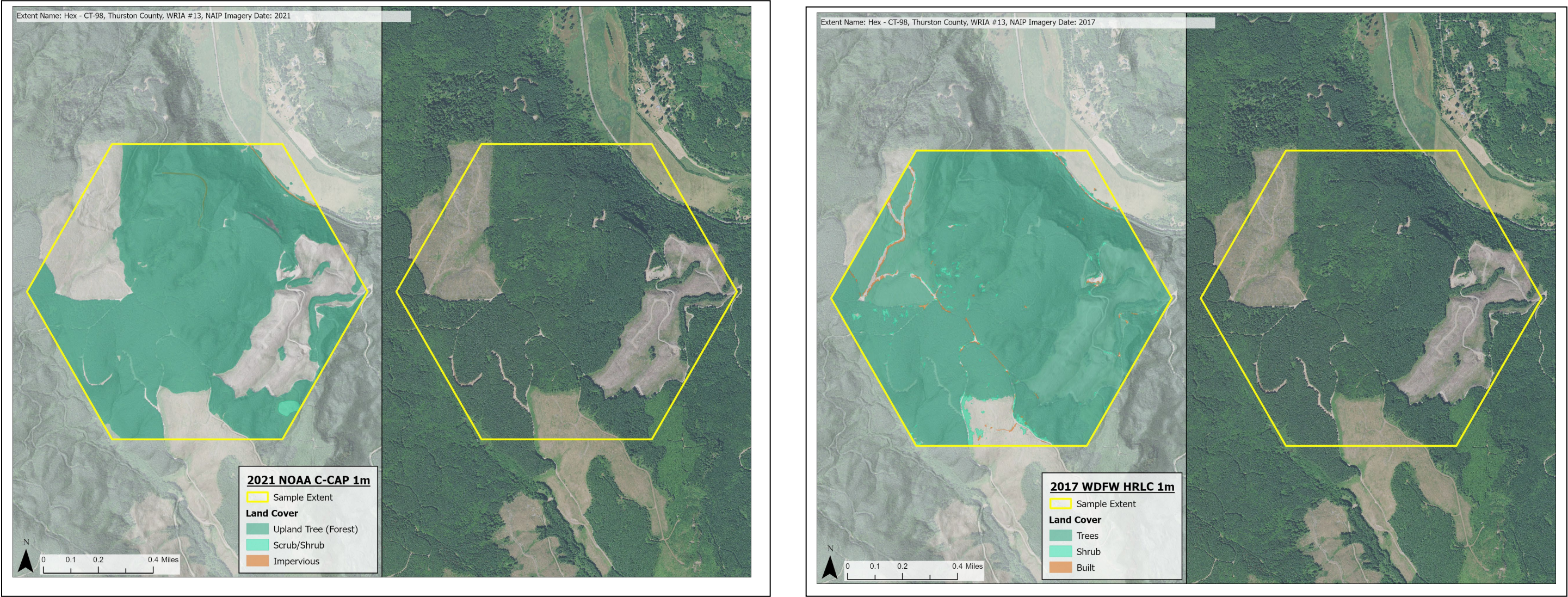
General Observations: This location shows 34% of the extent mapped as Upland Tree (Forest) and 0% Scrub/Shrub for 2021 NOAA C-CAP 1m vs 33% of the extent mapped as Trees and 6% Shrub for the 2017 WDFW HRLC. Similarly, 4% of the extent is mapped as Impervious for NOAA C-CAP while 4% of the extent is mapped as Built for WDFW HRLC.

Thurston County – Hex CR-80



General Observations: This location shows 2% of the extent mapped as Upland Tree (Forest) and 0% for 2021 NOAA C-CAP 1m vs 2% of the extent mapped as Trees and 0% Shrub for the 2017 WDFW HRLC. Similarly, 0% of the extent is mapped as Impervious for NOAA C-CAP while 0% of the extent is mapped as Built for WDFW HRLC.

Thurston County – Hex-CT-98



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