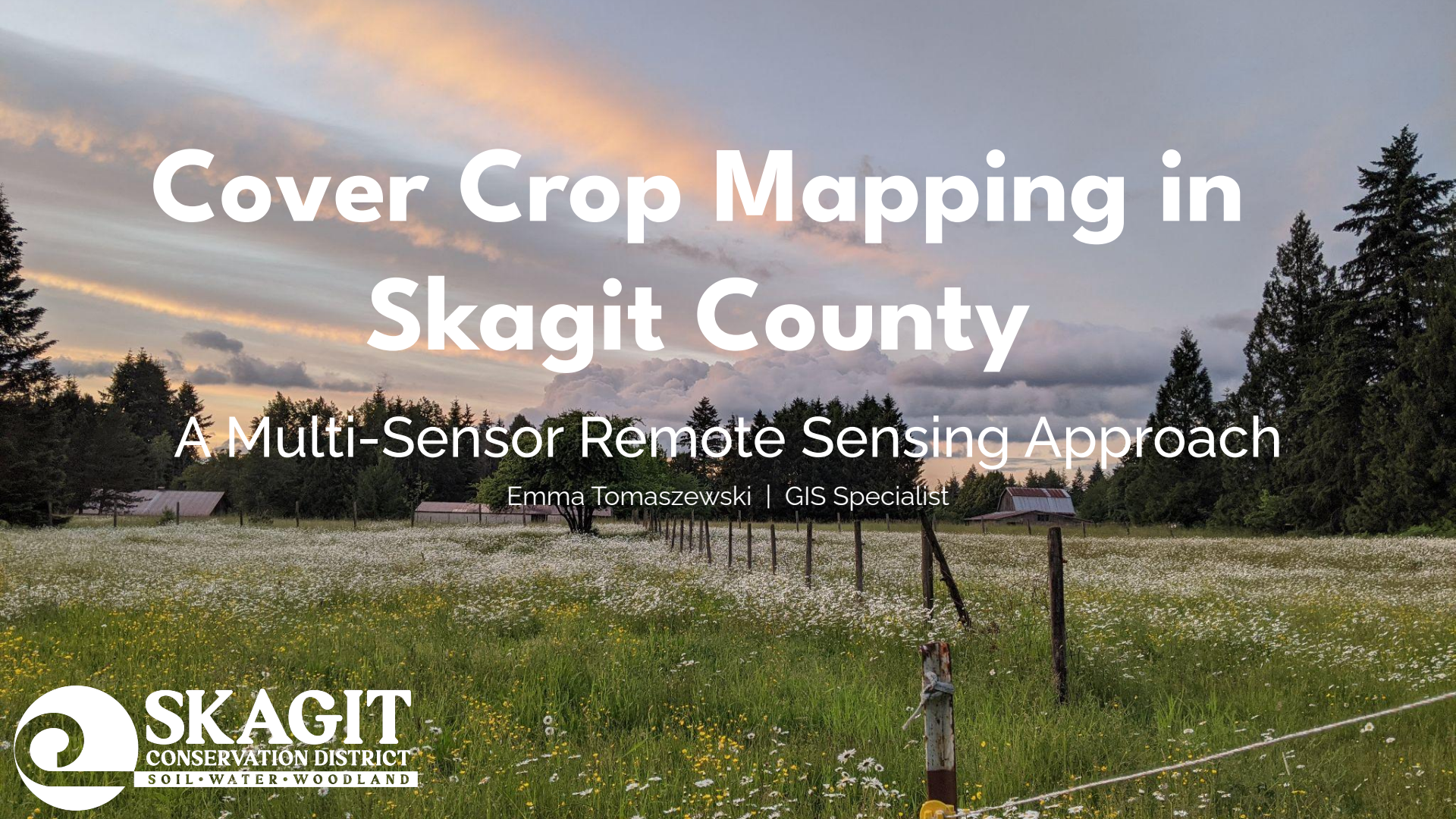

Cover Crop Mapping in Skagit County

A Multi-Sensor Remote Sensing Approach

Emma Tomaszewski | GIS Specialist

SKAGIT CONSERVATION DISTRICT
SOIL • WATER • WOODLAND

Emma Tomaszewski | GIS Specialist, Skagit Conservation District

- Background in Wildlife Ecology Research and Spatial Analysis
- MSc in Conservation Ecology
- Current Focus: cartography, remote sensing, and web GIS for conservation outreach

SKAGIT CONSERVATION DISTRICT

SOIL • WATER • WOODLAND

SKAGIT CONSERVATION DISTRICT
SOIL • WATER • WOODLAND

Conservation Districts

- Established as a direct response to the Dust Bowl (1930s)
- Special purpose districts
  - locally governed
  - non-regulatory
- Most counties in the US have one

Credit: National Association of Conservation Districts

SKAGIT CONSERVATION DISTRICT
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Local Partners

- Serve, educate and support local
  - Farmers
  - Ranchers
  - Land managers
- Promoting stewardship
  - Protect land and water resources

SKAGIT CONSERVATION DISTRICT
SOIL • WATER • WOODLAND

Stewardship of Skagit County's natural resources

- Clean water and healthy, productive landscapes
  - Farming
  - Forestry
  - Restoration

Sustainable Agriculture & Soil Health

- Skagit is one of Western Washington's most productive agricultural counties

Sustainable Agriculture & Soil Health

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- Agriculture puts pressure on soil health, water quality and habitat

Sustainable Agriculture & Soil Health

- Skagit is one of Western Washington's most productive agricultural counties
- Agriculture puts pressure on soil health, water quality and habitat
- Work directly with farmers to voluntarily adopt practices to reduce impacts
    - Best Management Practices (BMPs)

Cover Crops

Cover Crops

- Planted between cash crop cycles to overwinter fields

Cover Crops

A Farmers Best Management Practice to:

- Promote erosion control
- Reduce runoff
- Maintain soil nutrient cycling and structure
- Lower water pollution risks

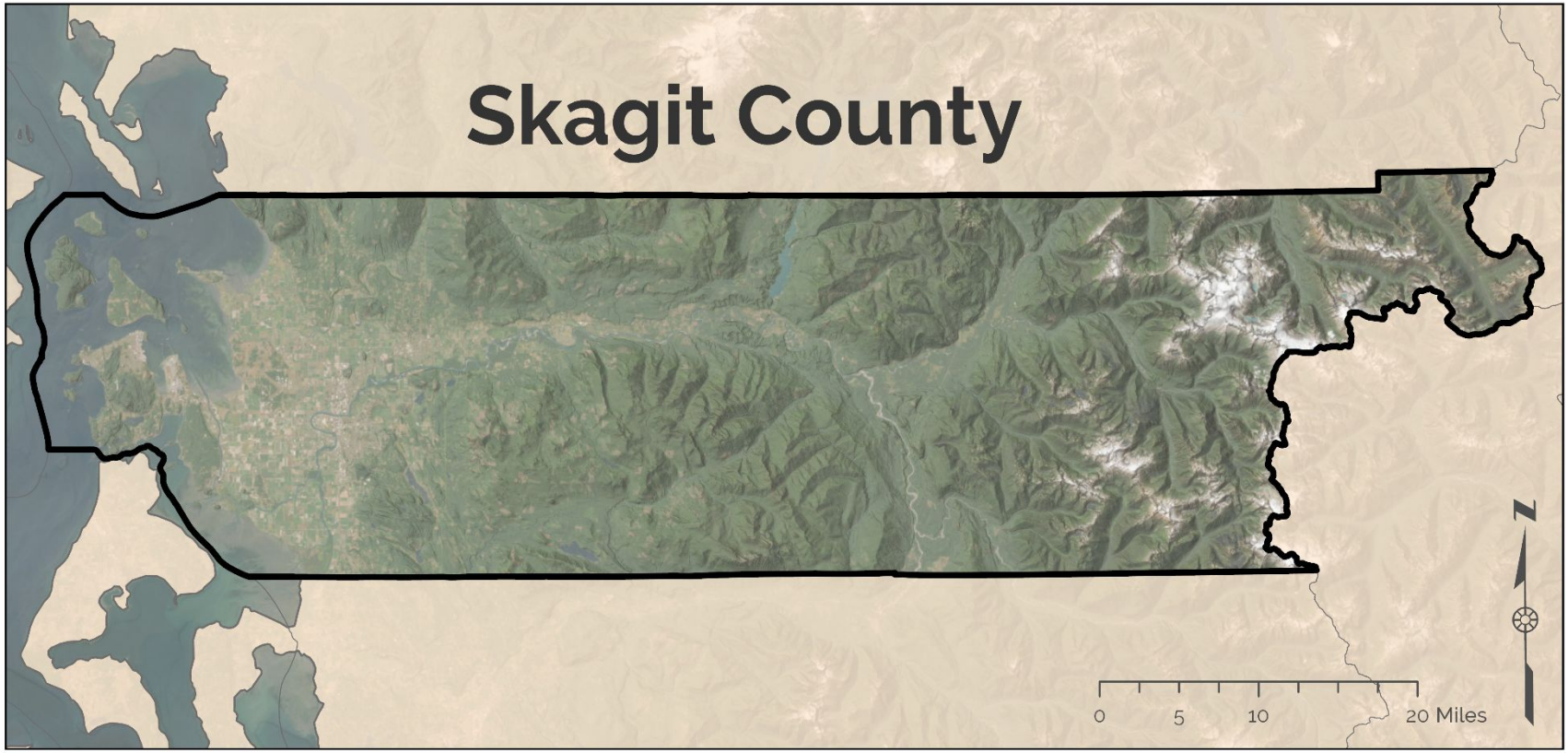
Cover Crops

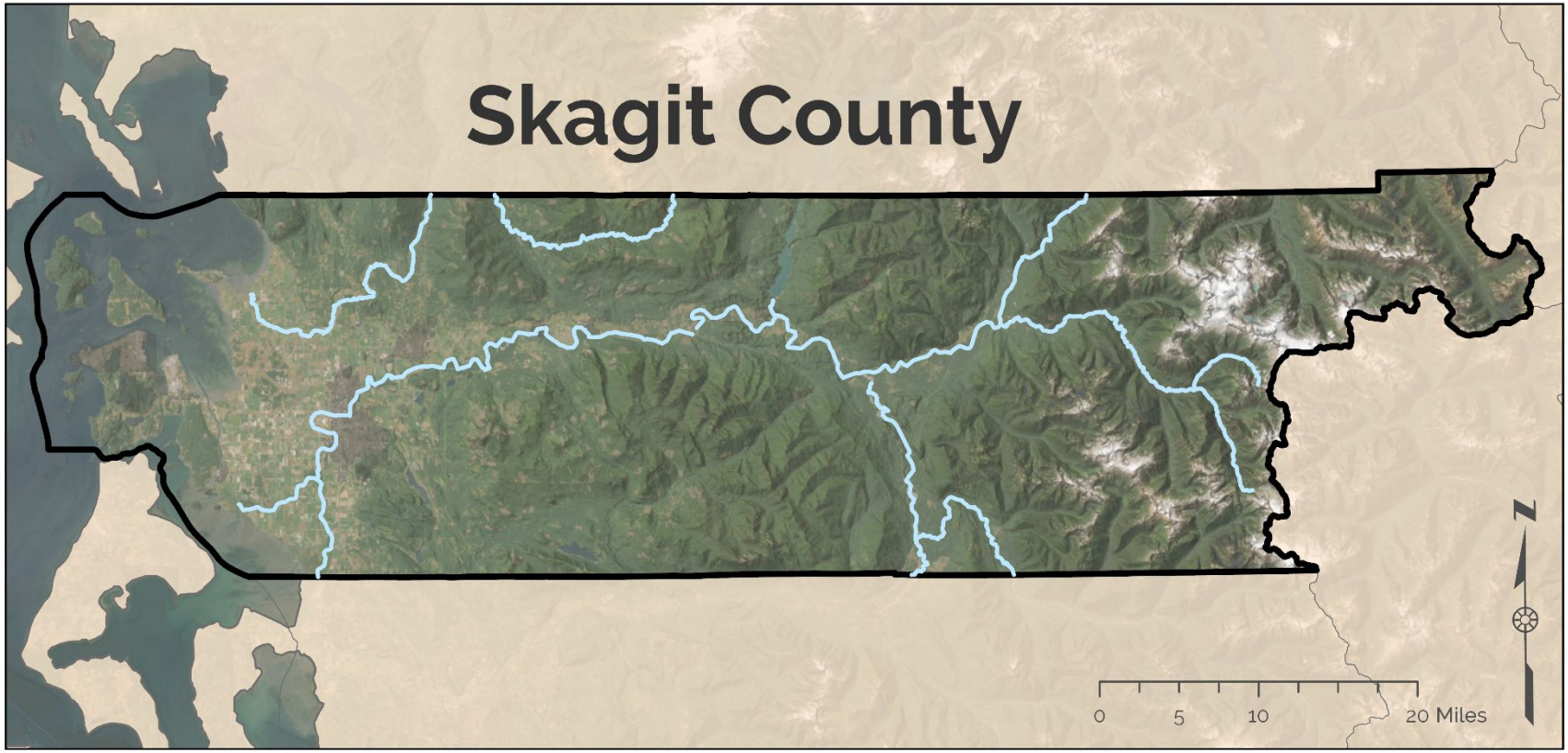
- Planted between cash crop cycles to overwinter fields
- A Farmers Best Management Practice to:
  - Promote erosion control
  - Reduce runoff
  - Maintain soil nutrient cycling and structure
  - Lower water pollution risks
- Indicator of conservation adoption

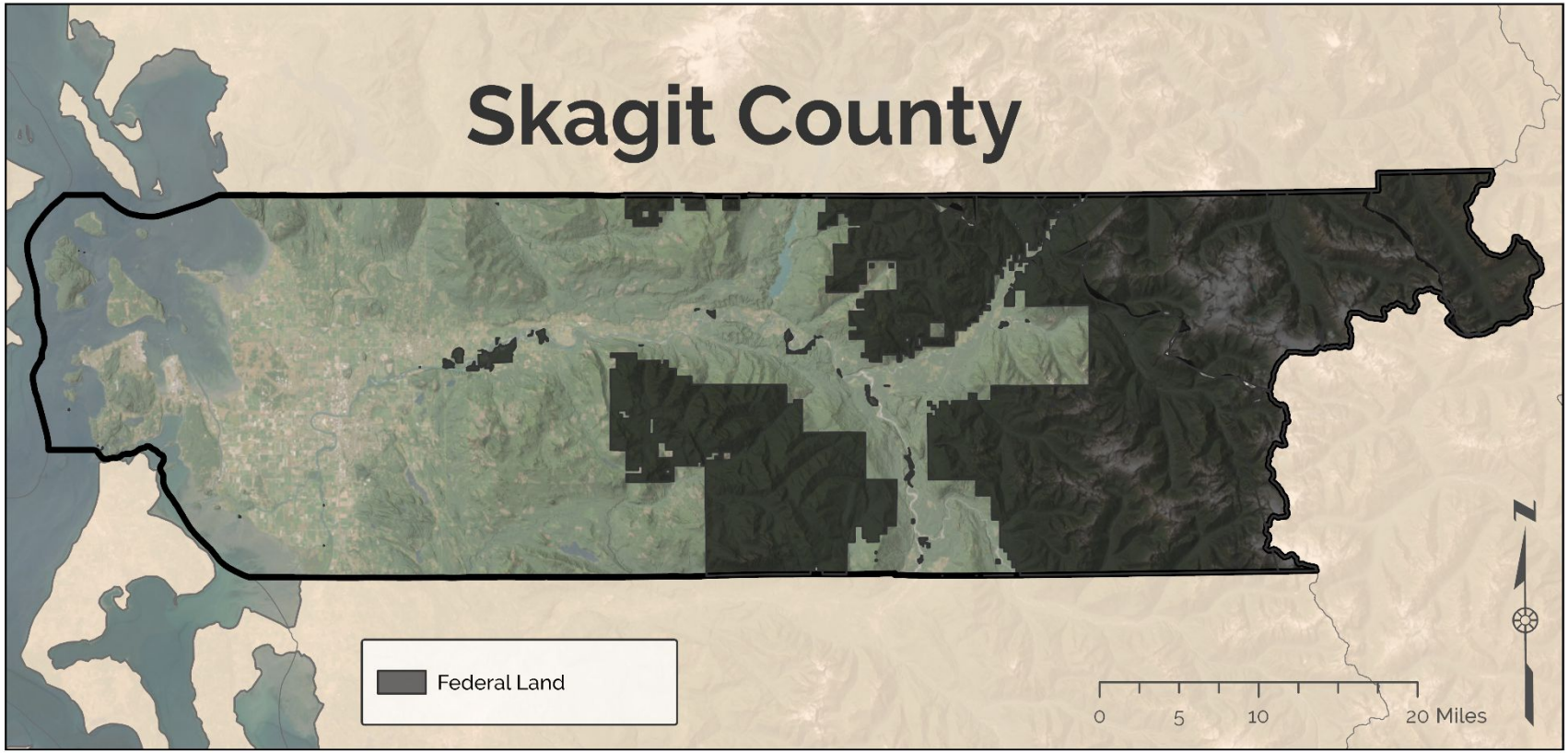
Project Goals

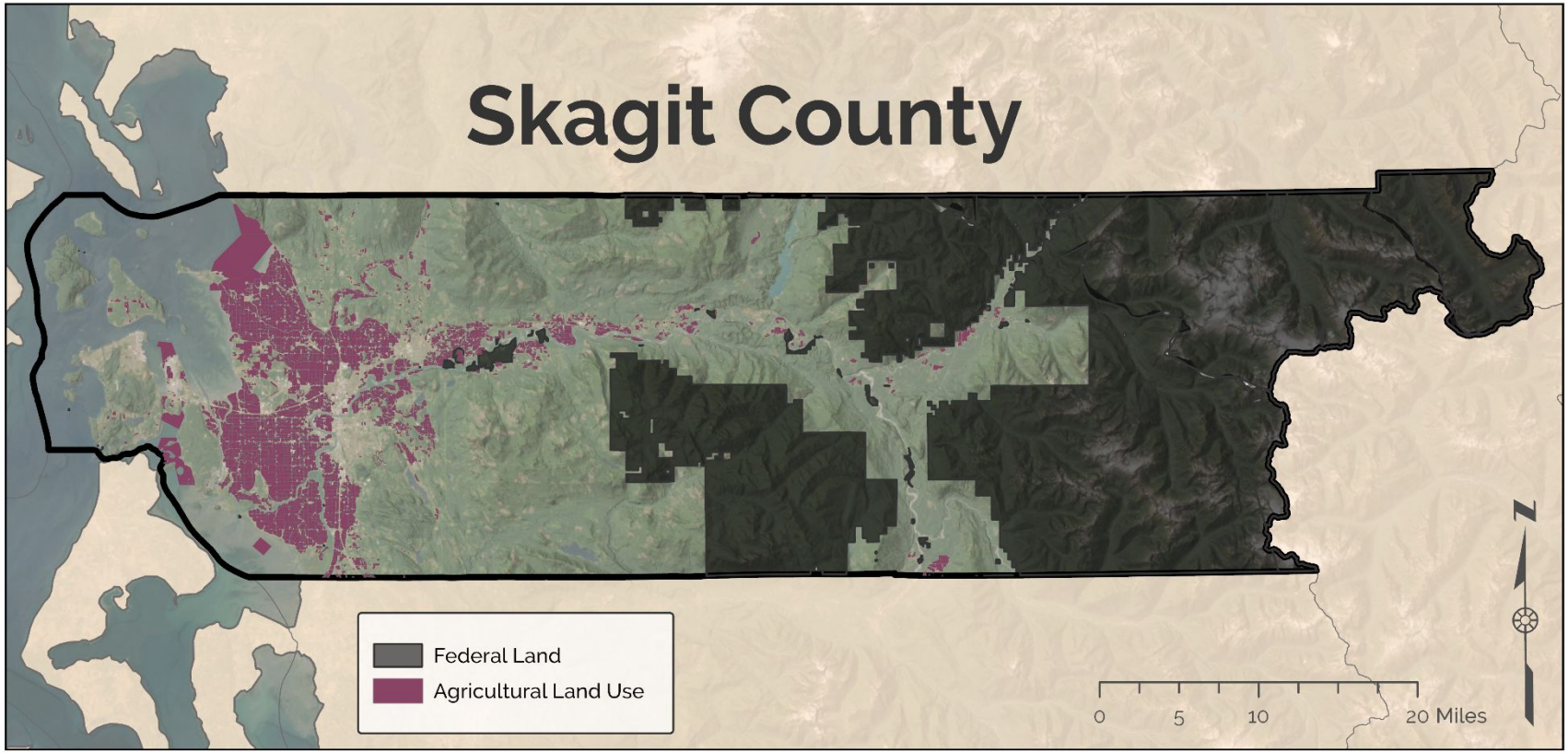
- Track cover crop adoption across Skagit County
- Identify long-term trends in conservation practices
- Compare known adopters (Skagit CD clients) against county-wide trends
- Deliver accessible education and outreach tools for farmers + landowners

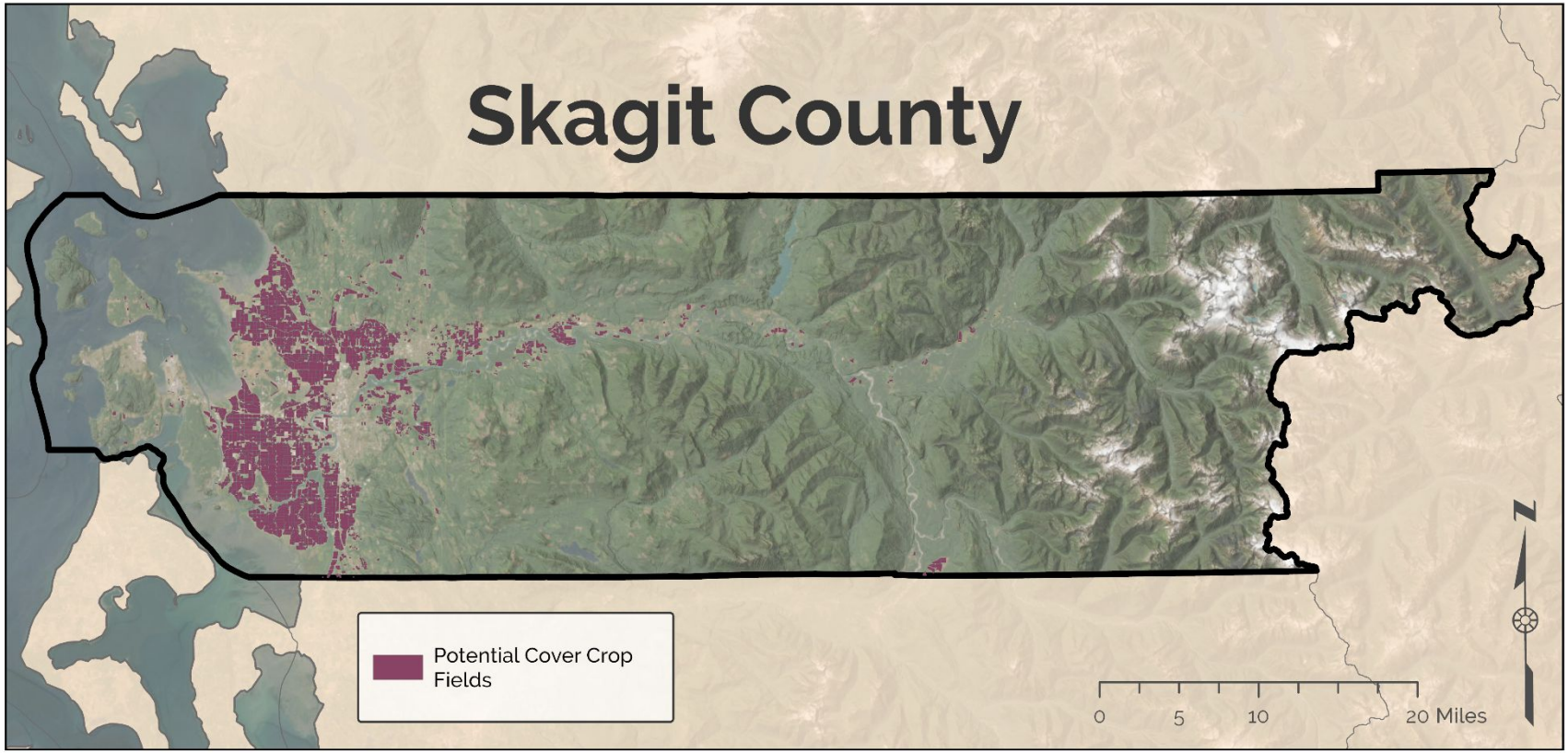
Study Area

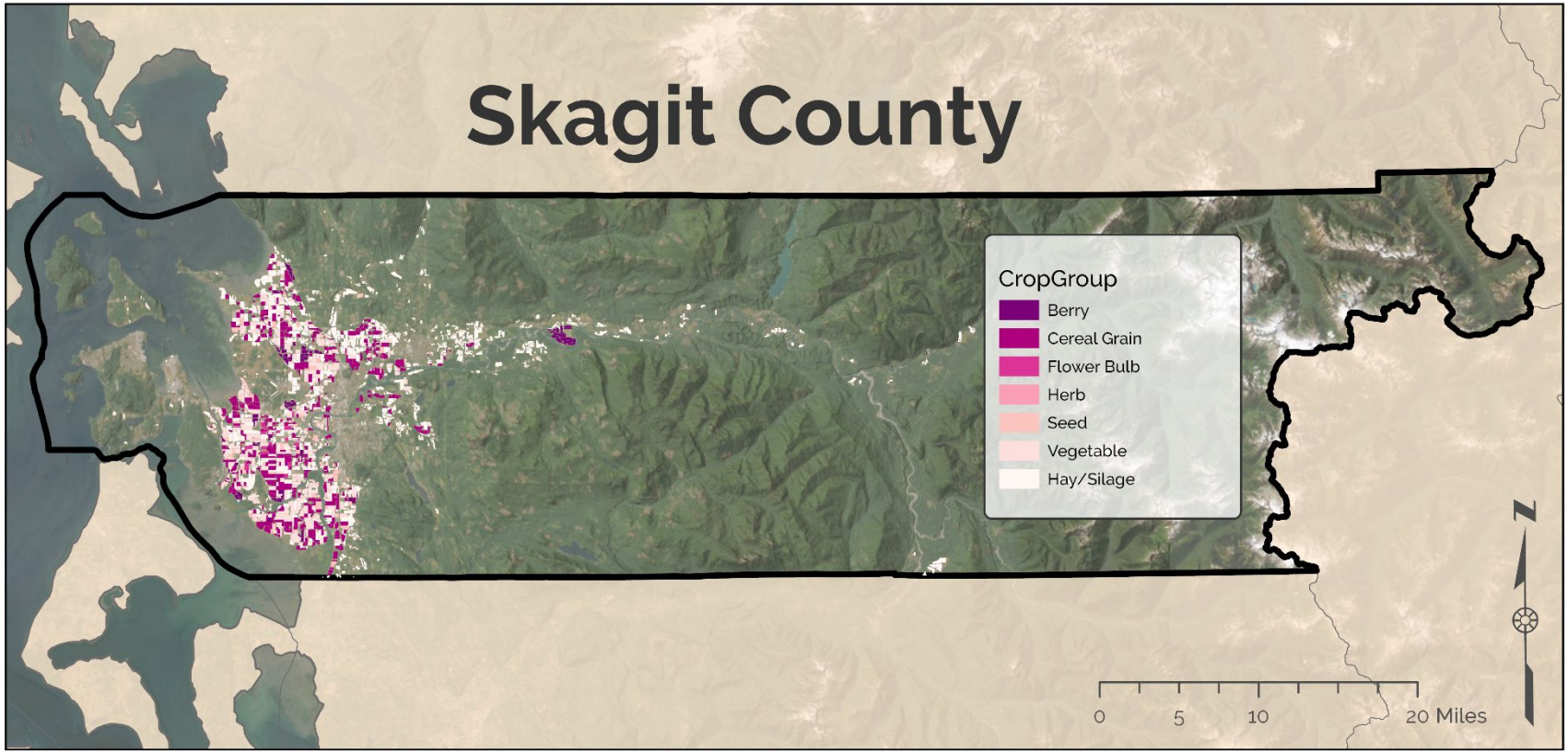

Skagit County
N
0
5
10
20 Miles

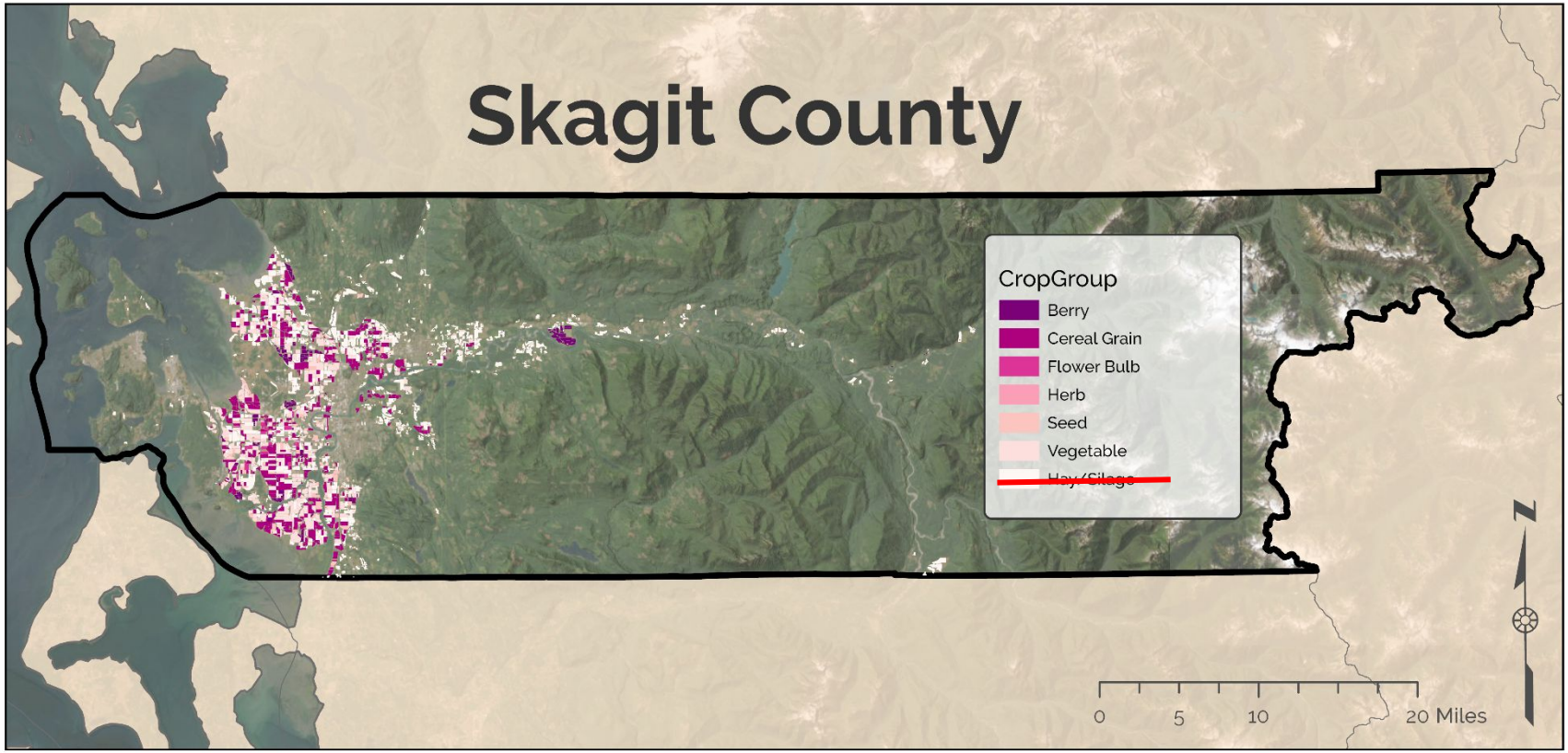

Skagit County
0
5
10
20 Miles
N

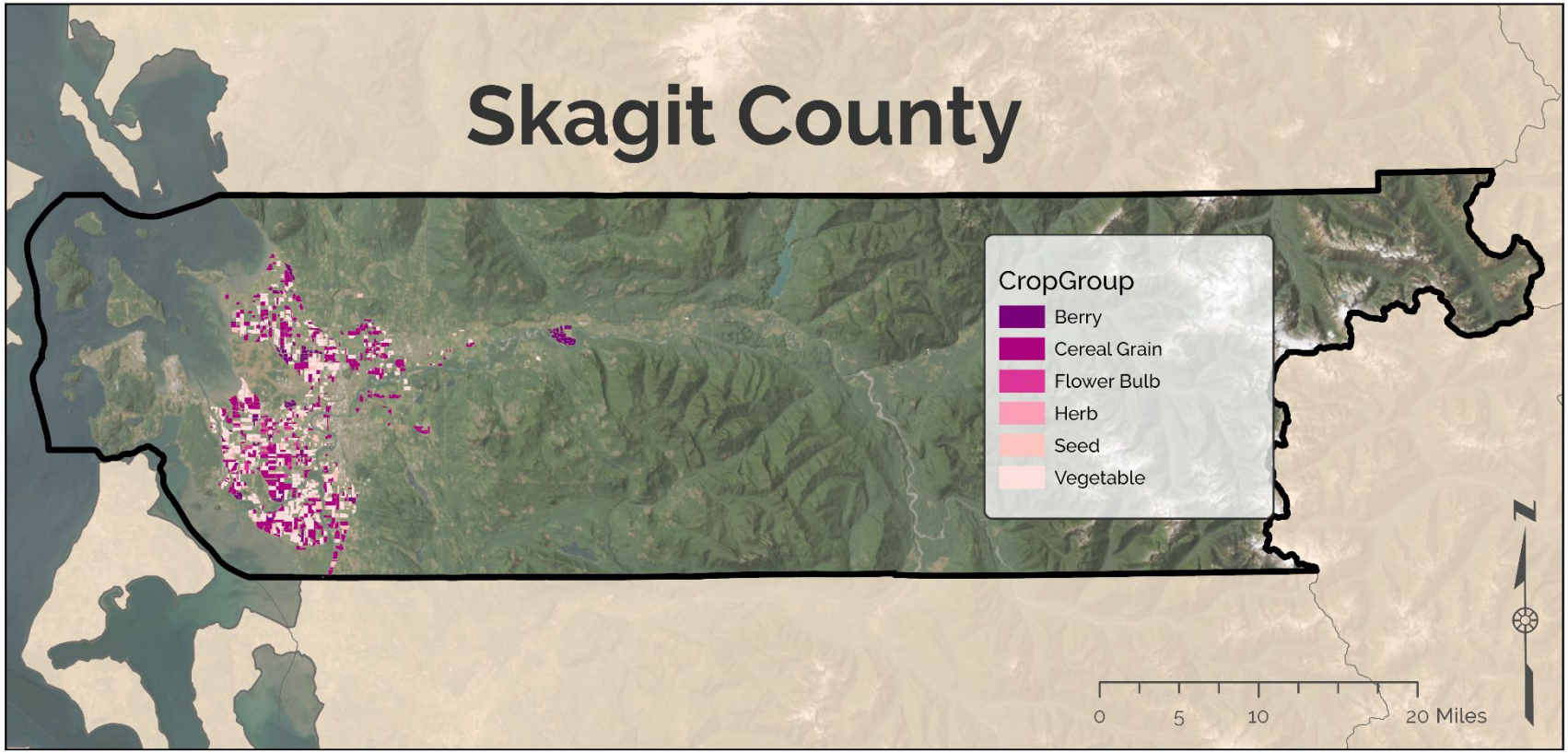

Skagit County
Federal Land
0
5
10
20 Miles
N

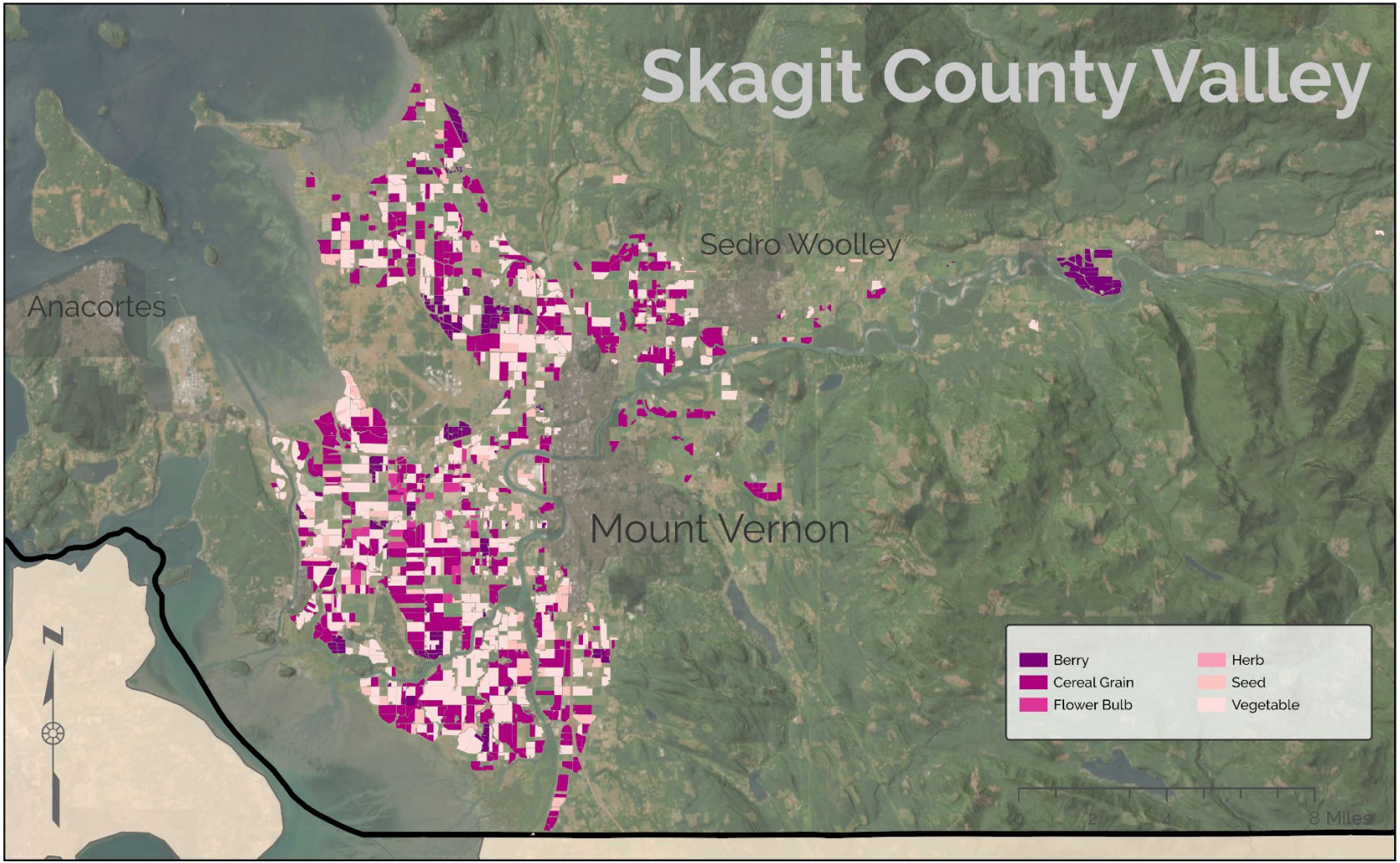

Skagit County
Federal Land
Agricultural Land Use
N
0
5
10
20 Miles


Skagit County
Potential Cover Crop Fields
0
5
10
20 Miles
N


Skagit County
CropGroup
Berry
Cereal Grain
Flower Bulb
Herb
Seed
Vegetable
Hay/Silage
N
0
5
10
20 Miles


Skagit County
CropGroup
Berry
Cereal Grain
Flower Bulb
Herb
Seed
Vegetable
Hay/Silage
N
0
5
10
20 Miles


Skagit County
CropGroup
Berry
Cereal Grain
Flower Bulb
Herb
Seed
Vegetable
N
0
5
10
20 Miles


Skagit County Valley
Sedro Woolley
Anacortes
Mount Vernon
N
Berry
Cereal Grain
Flower Bulb
Herb
Seed
Vegetable
0
2
4
8 Miles

Winter Data Acquisition

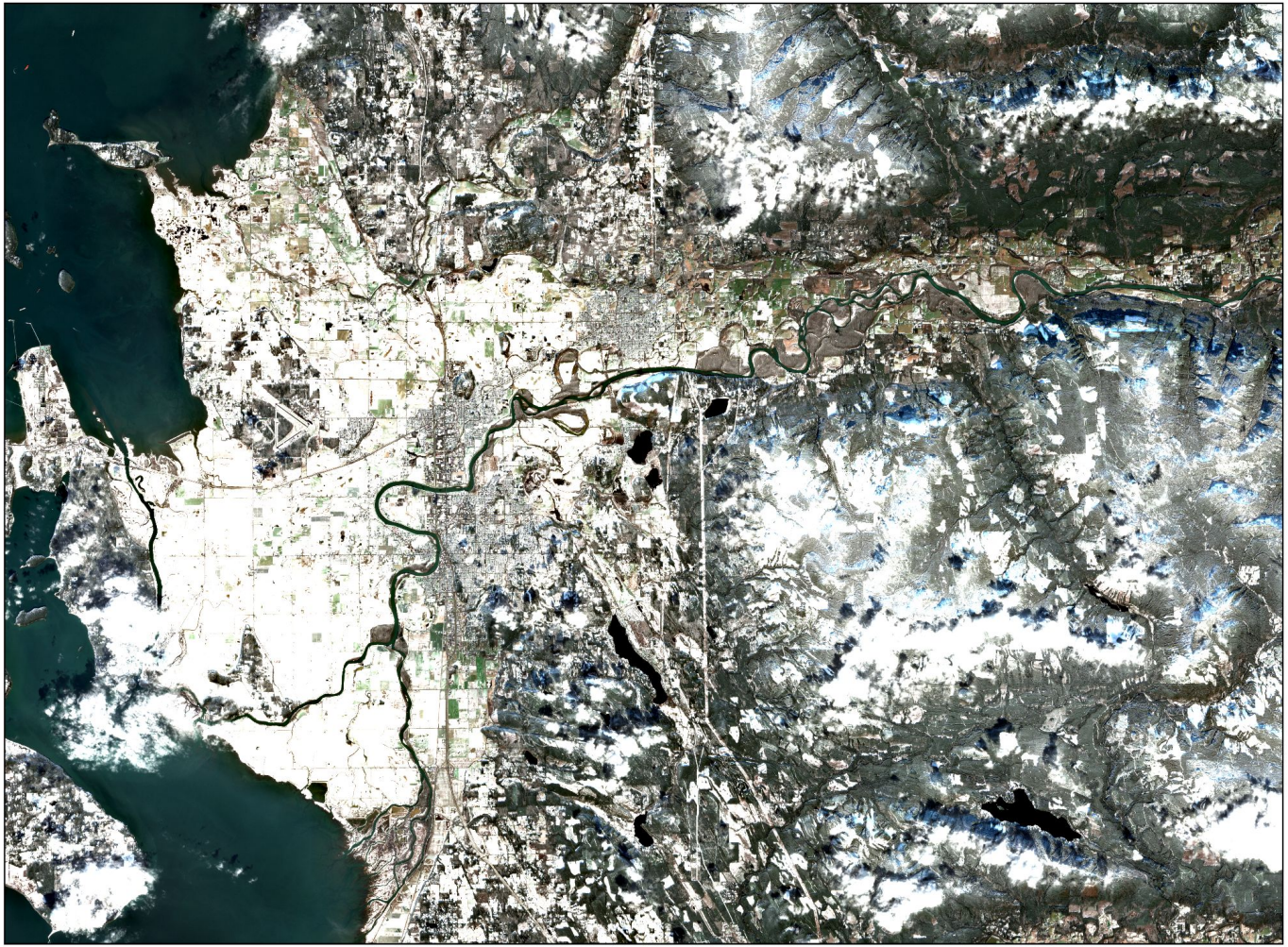
- November 1st - February 28th

Winter Data Acquisition

- November 1st - February 28th
  - Cover crops planted from September - mid October

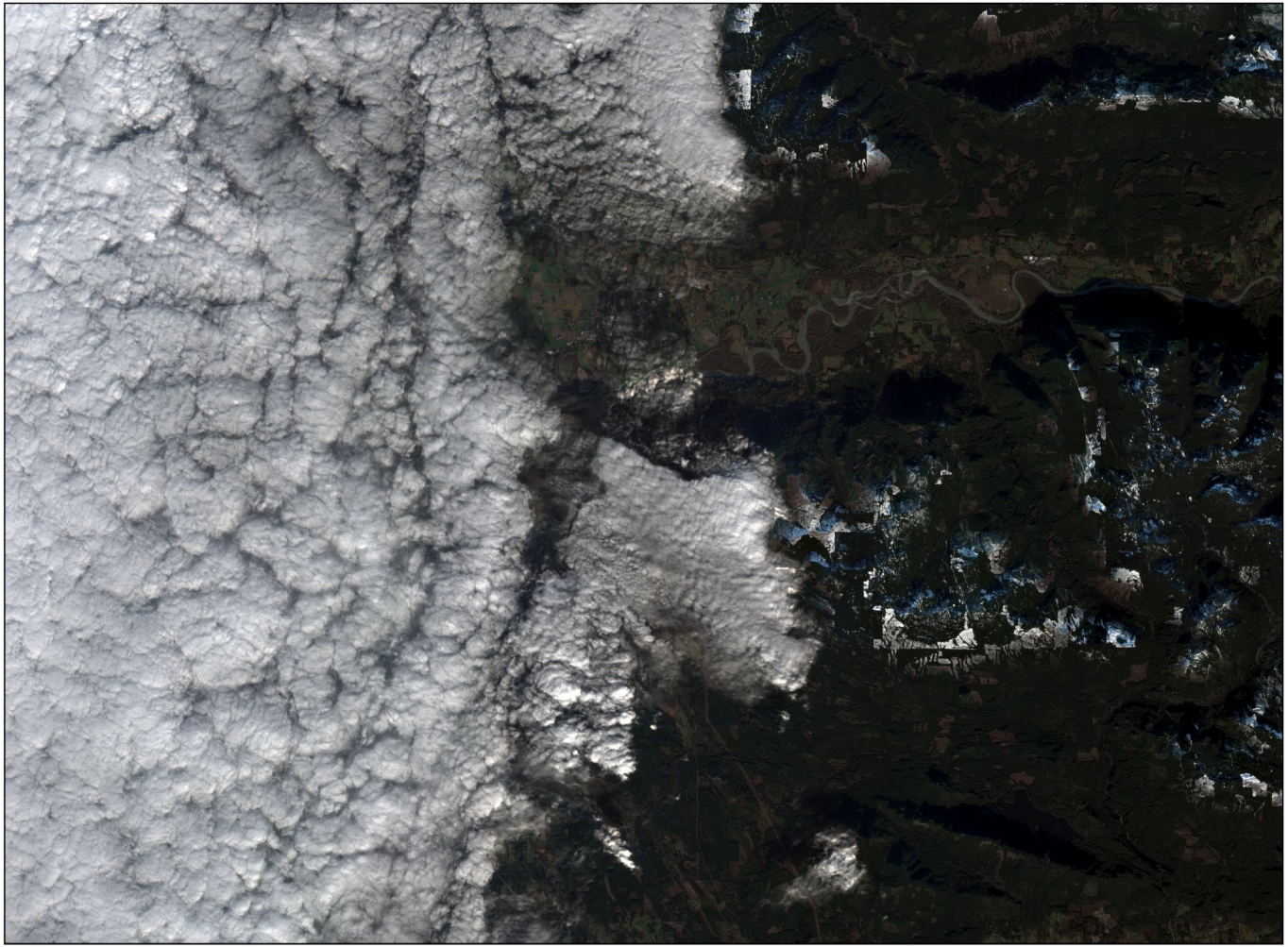
Winter Data Acquisition

- November 1st - February 28th
  - Cover crops planted from September - mid October
  - Farmers typically plant cash crops starting in March



Winter 2022

Winter Data Acquisition Challenges

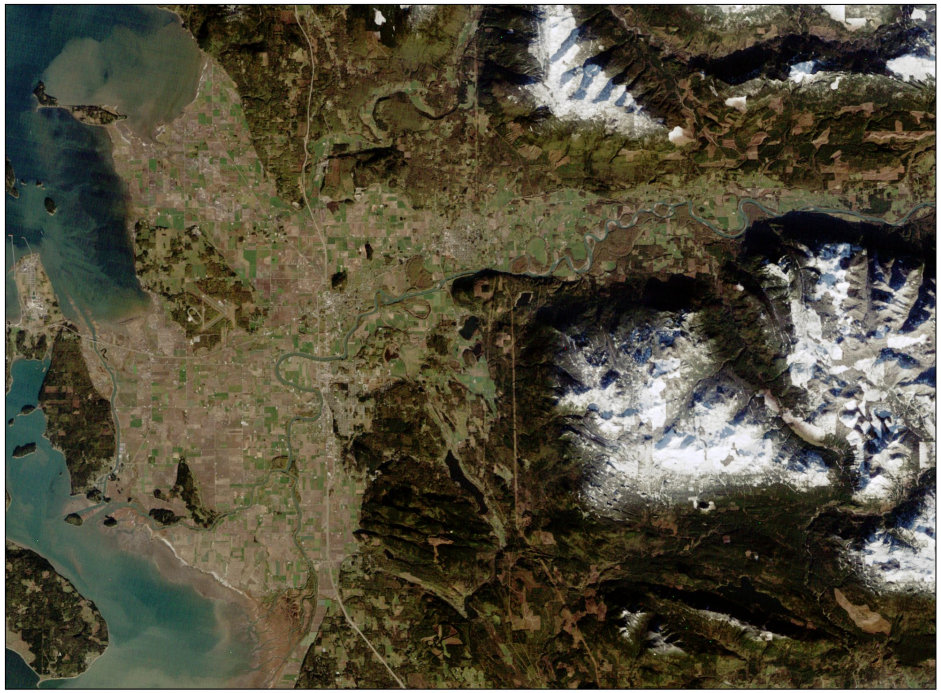


Winter 2026

Winter Data Acquisition Challenges

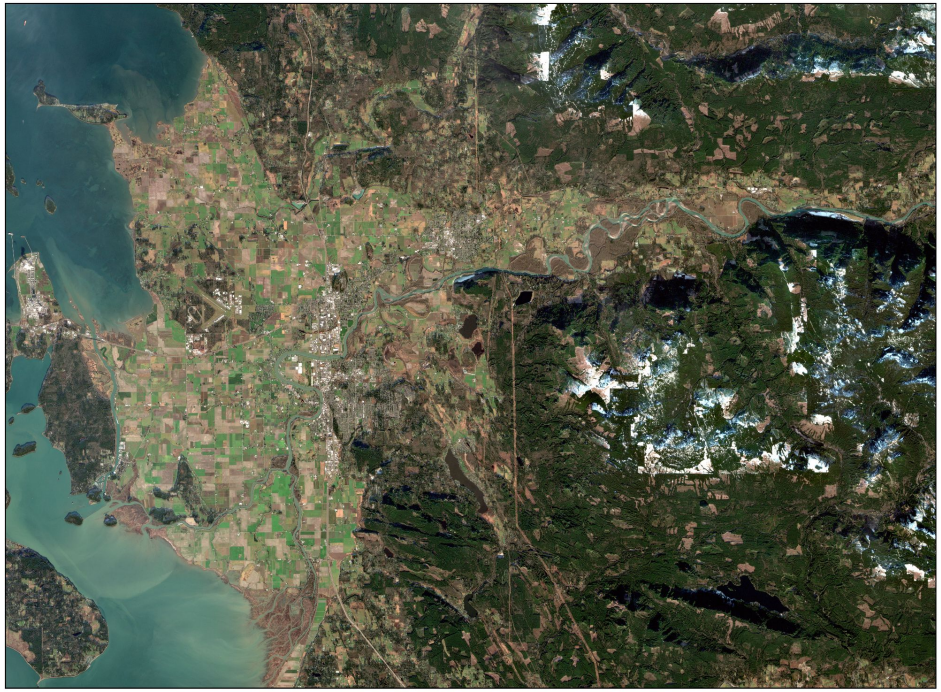
40 Years of Data

Landsat 5



Winter 1986

Sentinel 2



Winter 2026

To determine Cover Crop Adoption we will look at

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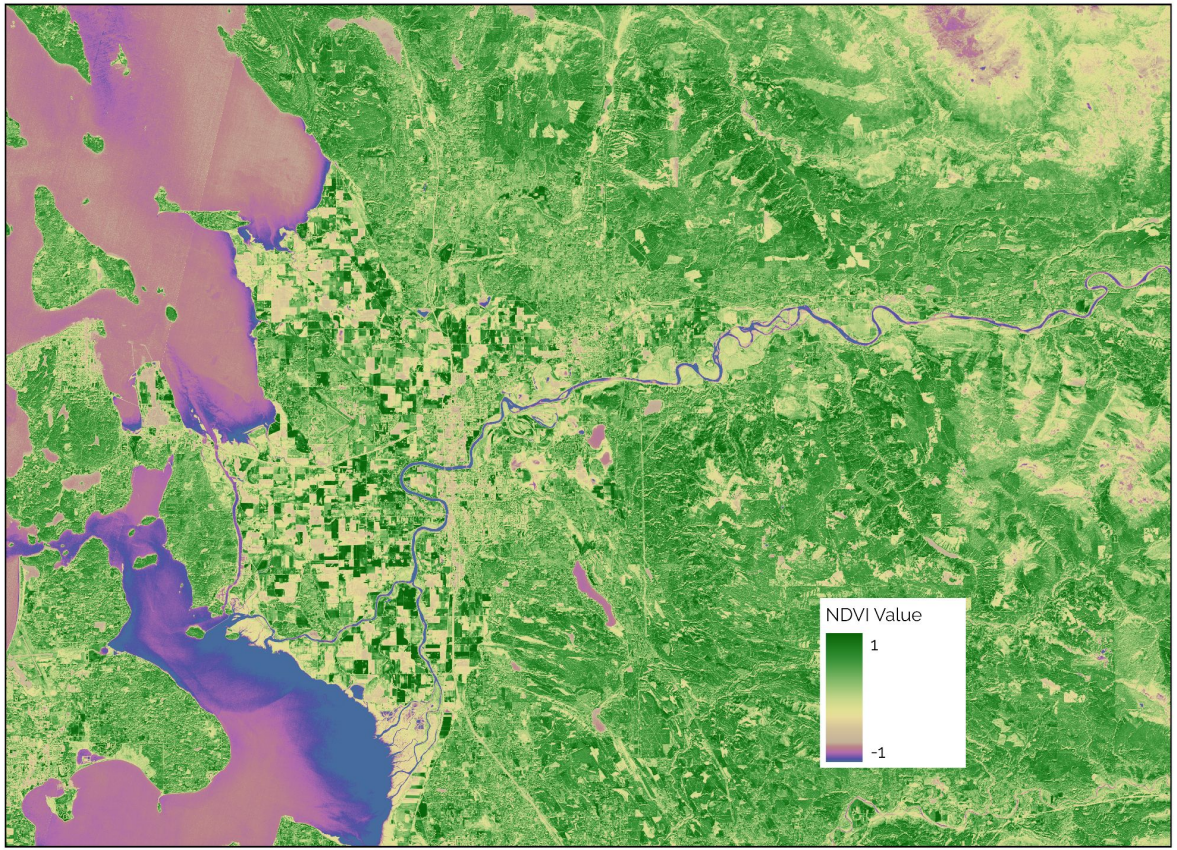
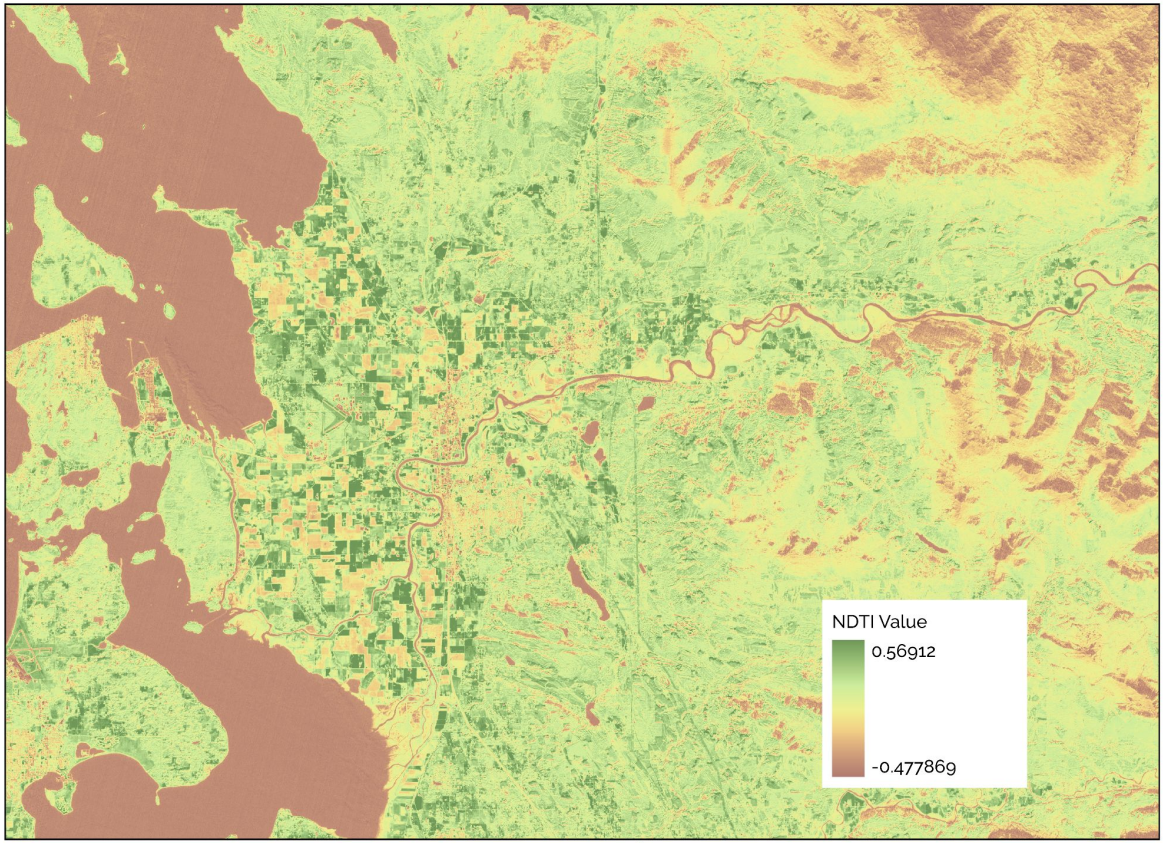


Winter 2026 Sentinel 2

Normalized Difference Vegetation Index (NDVI)

- How green are the fields vs bare soil

To determine Cover Crop Adoption we will look at



Winter 2026 Sentinel 2

Normalized Difference Tillage Index (NDTI)

- Measures Crop Residue

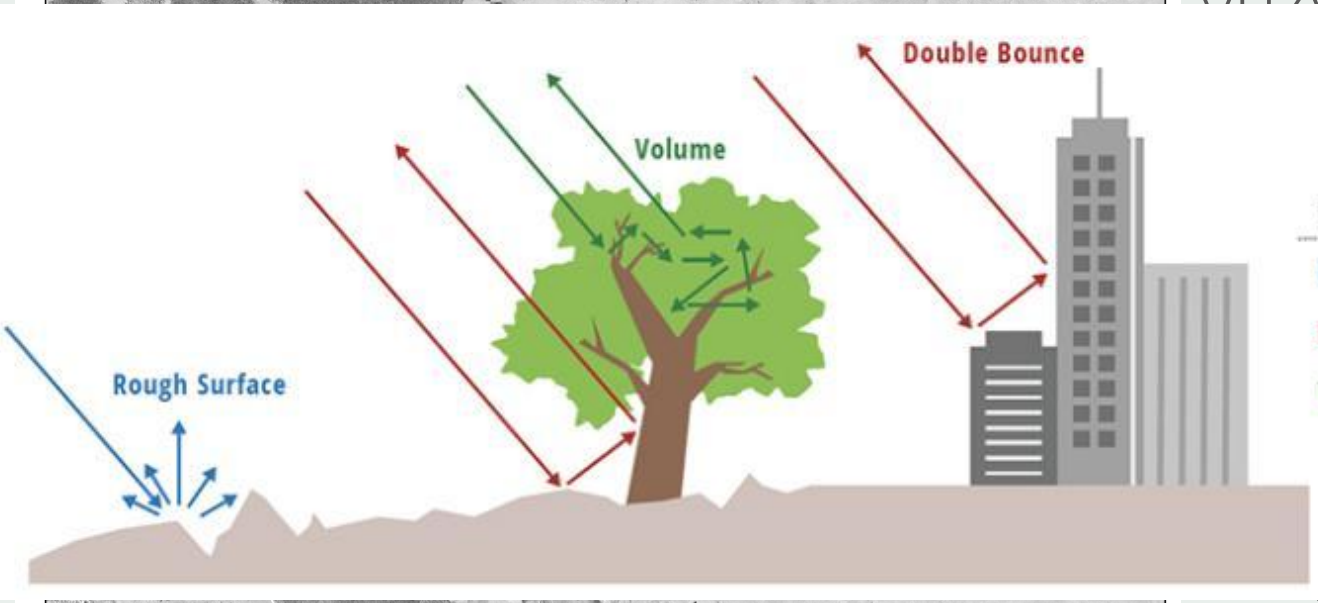
To determine Cover Crop Adoption we will look at

Skagit County | Winter 2026 VH/VV

VH/VV (backscatter) Ratio

- VV (vertical-vertical) surface scattering (roughness)
  - Good for detecting bare soil
- VH (vertical-horizontal) volume scattering
  - Good for detecting vegetation

To determine Cover Crop Adoption we will look at



RELATIVE SCATTERING STRENGTH BY POLARIZATION:

Rough Surface Scattering	$\|S_{VV}\| > \|S_{HH}\| > \|S_{HV}\|$ or $\|S_{VH}\|$
Double Bounce Scattering	$\|S_{HH}\| > \|S_{VV}\| > \|S_{HV}\|$ or $\|S_{VH}\|$
Volume Scattering	Main source of $\|S_{HV}\|$ and $\|S_{VH}\|$

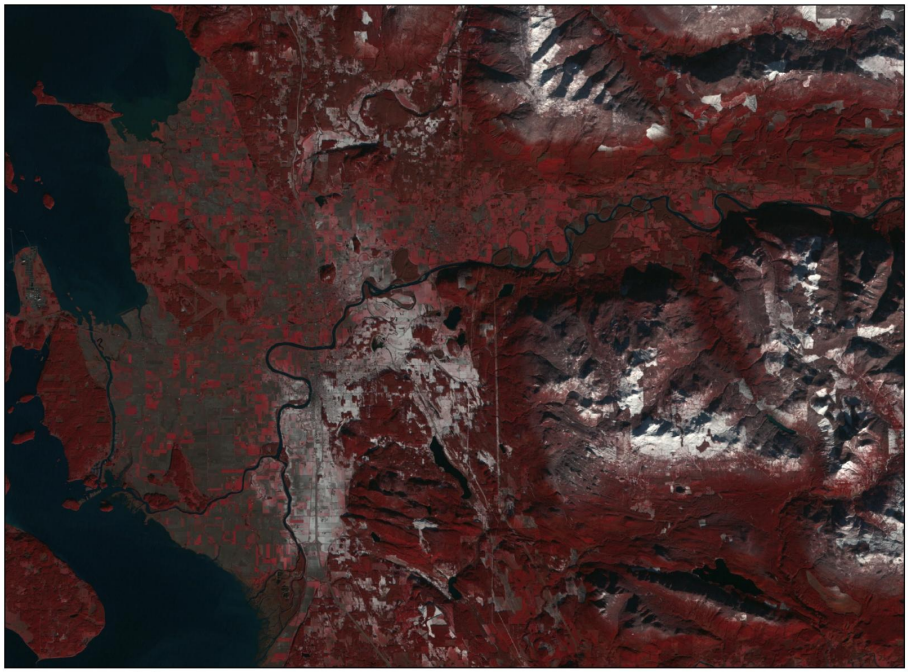
Credit: NASA

- VH/VV (backscatter) Ratio
- good for detecting vegetation

Skagit County | Winter 2026 VH/VV

The Sensors

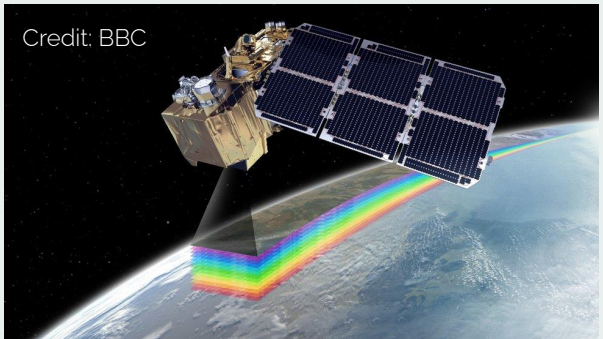
- **Landsat 5-9** — 1986 to present, 30m resolution
  - USGS Earth Explorer
  - NDVI
  - Long-term data

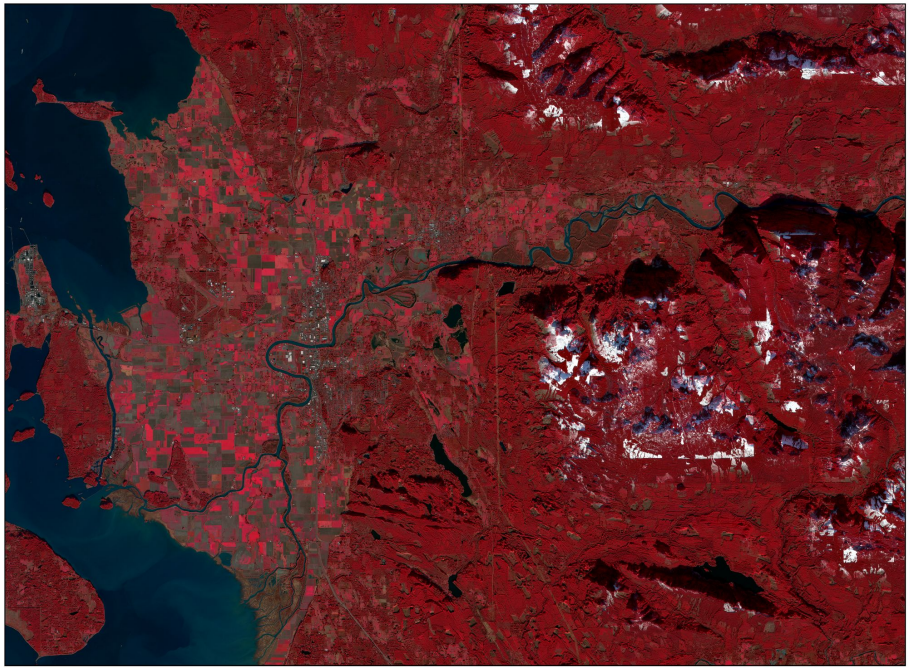


Winter 1986

The Sensors

- **Landsat 5-9** — 1986 to present, 30m resolution
  - USGS Earth Explorer
  - NDVI
  - Long term data
- **Sentinel-2** — 2017 to present, 10m resolution
  - Copernicus
  - NDVI + NDTI

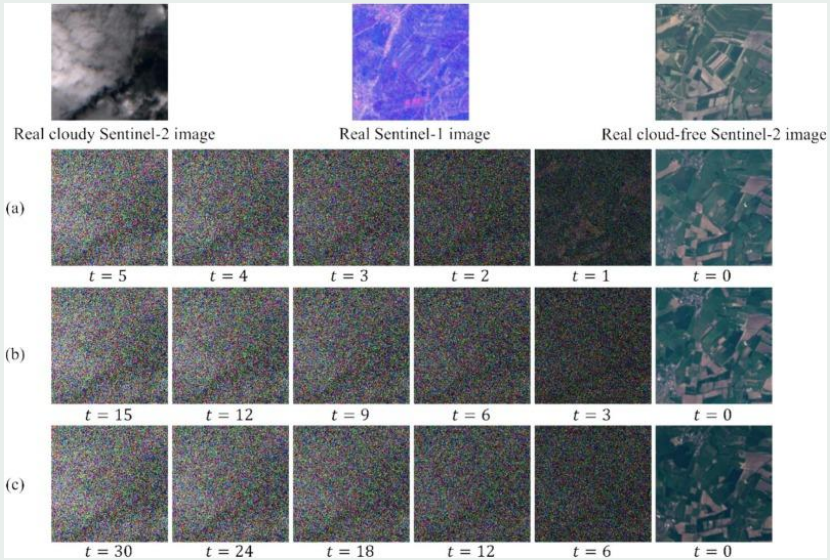




Winter 2018

The Sensors

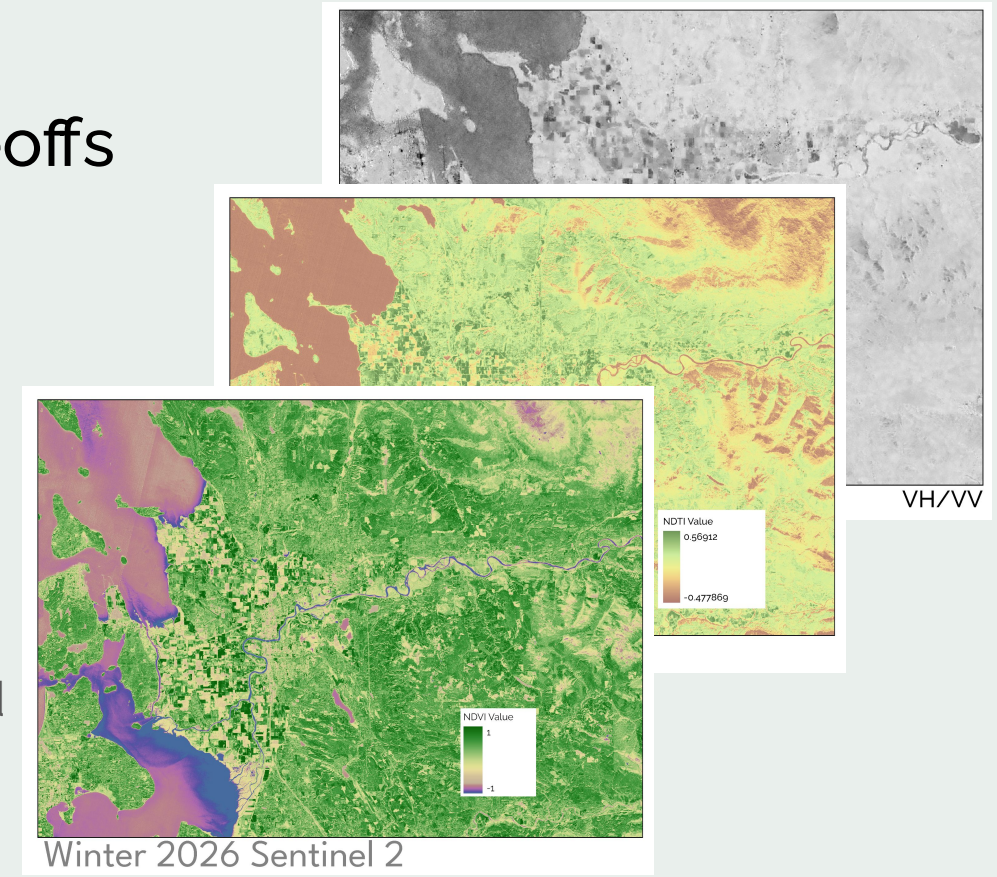
- **Landsat 5-9** — 1986 to present, 30m resolution
  - USGS Earth Explorer
  - NDVI
  - Long term data
- **Sentinel-2** — 2017 to present, 10m resolution
  - Copernicus
  - NDVI + NDTI
- **Sentinel-1 SAR** — Cloud-penetrating C-band radar
  - ASF HyP3
  - VH/VV ratio



Credit: Cai, J., Huang, B., Liu, H. Fusing Sentinel-1 and Sentinel-2 data with diffusion models for cloud removal, Remote Sensing of Environment. 2025. https://doi.org/10.1016/j.rse.2025.115049.

Sensors Strengths & Tradeoffs

- **Landsat**: temporal depth
  - 40+ years of continuity
- **Sentinel-2**: spatial detail
  - sharpest optical imagery
- **Sentinel-1 SAR**: cloud cover penetration
  - Critical for PNW winters
- Together: complete seasonal and historical coverage



Methodology

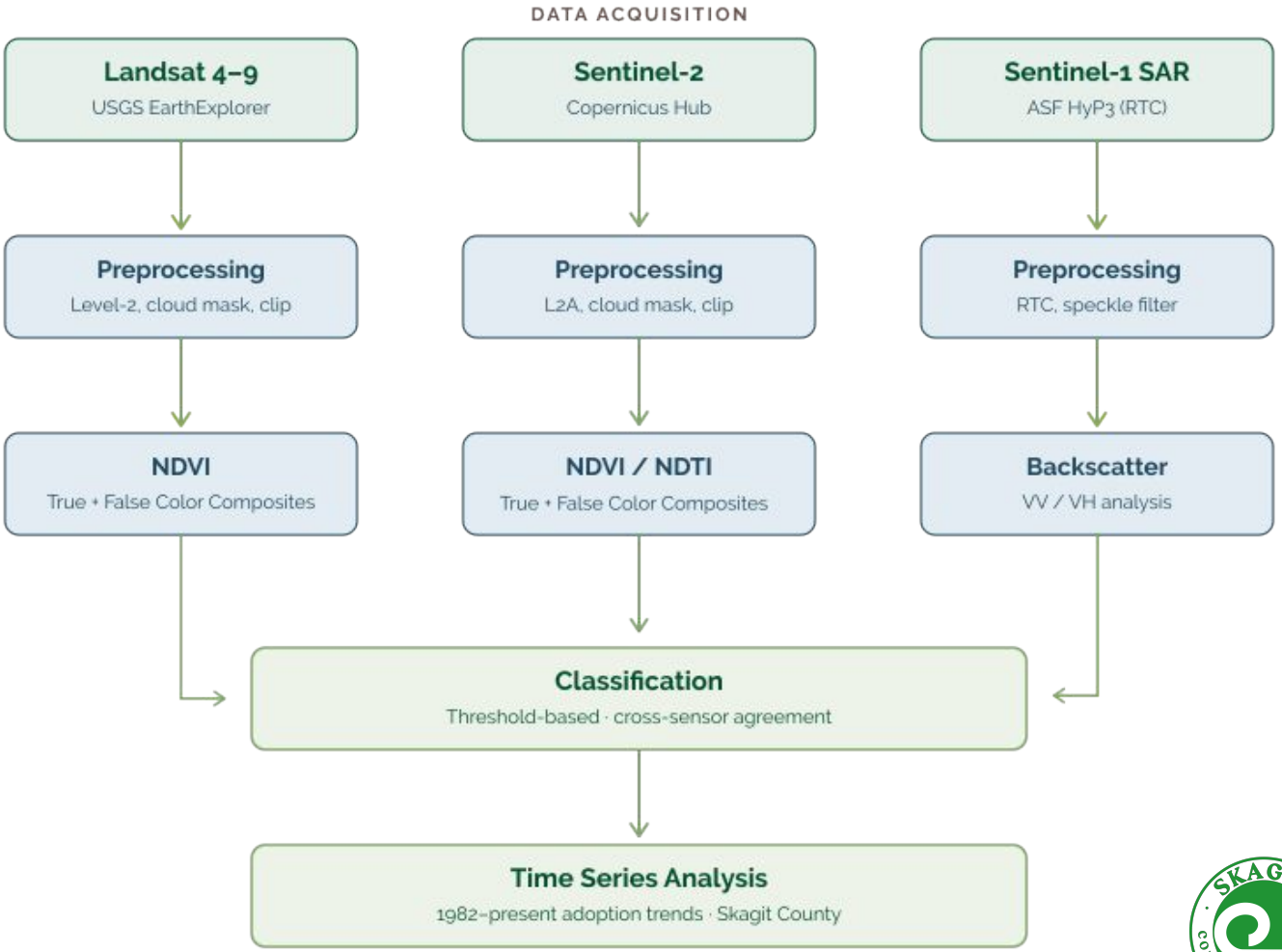


Image Processing

- When available, make composites of all images from same sensor and winter (nov 1 - feb 28)

Winter year	Landsat	Sentinel-1	Sentinel-2
2017	2	4	1
2018	1	8	2
2019	1	11	1
2020	1	10	1
2021	1	10	1
2022	2	6	2
2023	3	10	3
2024	3	10	1
2025	2	5	2
2026	3	3	4
Total	**19**	**77**	**18**

Satellite Acquisition Days By Sensor and Winter Year

Image Processing

- Apply Cloud and Snow masking
- Calculate NDVI
  - distinguish bare soil vs vegetated surface
- Calculate NDTI (Sentinel-2 only)
  - added tillage discrimination
- Calculate VH/VV ratio (Sentinel-1 SAR)

```
"""
Sentinel-2 Level-2A Processing Script
=====================================
Processes Sentinel-2 L2A data downloaded from Copernicus/ESA.

Steps performed for each scene:
  1. Locate band files within the .SAFE folder structure
  2. Apply scale factor to convert integer DN to surface reflectance
  3. Calculate NDVI from B04 (Red) and B08 (NIR) at 10m resolution
  4. Calculate NDTI from B11 (SWIR1) and B12 (SWIR2) at 20m native resolution
  5. Organise outputs into Processed/YYYY/ folder
  6. Move raw .SAFE folders into Raw/YYYY/ folder
```

```
Sentinel-1 RTC Processing Script
================================
Processes Sentinel-1 RTC data downloaded from ASF Vertex.

Steps performed for each scene:
  1. Locate VH and VV GeoTIFF files (handles nested folder structure)
  2. Calculate VH/VV ratio (dB subtraction: VH - VV)
  3. Organise outputs into Processed/YYYY/ folder
  4. Move raw scene folders into Raw/YYYY/ folder
```

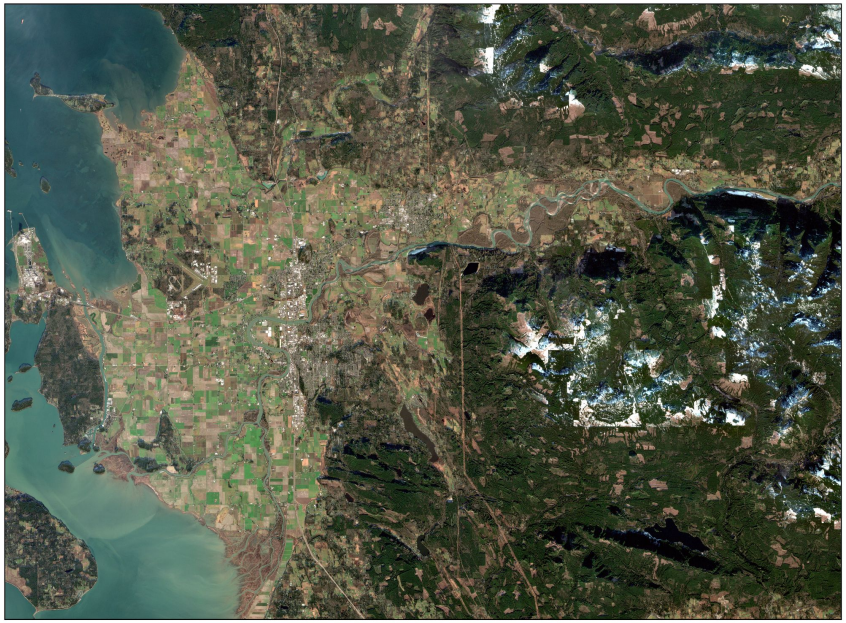
```
"""
Landsat Collection 2 Level-2 Processing Script
==============================================
Processes Landsat 4-5 TM, 7 ETM+, 8 OLI, and 9 OLI data.

Steps performed for each scene:
  1. Apply scale factors to convert integer DN to surface reflectance
  2. Apply QA_PIXEL cloud/shadow/snow mask
  3. Calculate NDVI
  4. Move all raw input files into an organised Raw folder structure
```

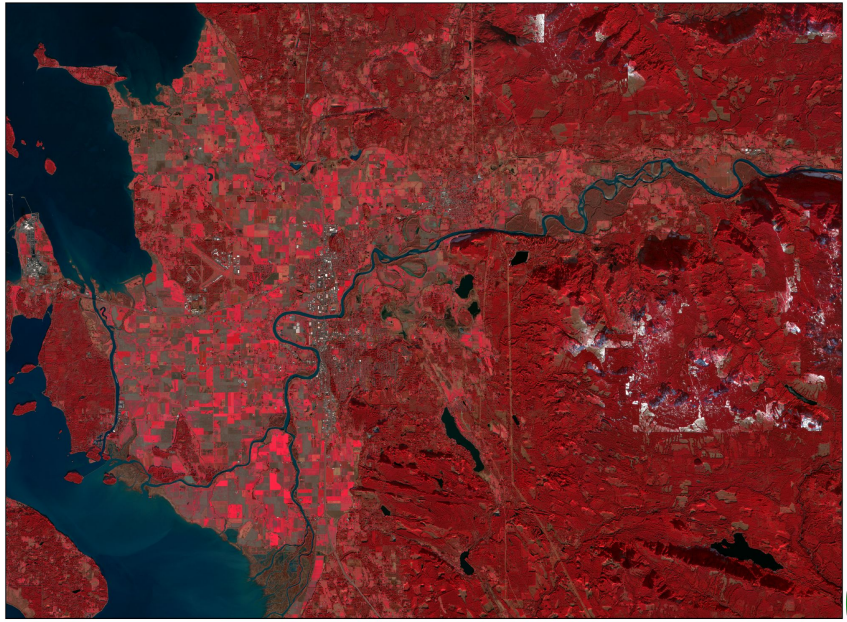
*Anthropic AI was used to assist with Python coding for image processing

Image Processing

- Create True and False Color composites
  - For final story/web map output



Winter 2026



Winter 2026

Cover Crop Classification Thresholds

NDVI CLASSIFICATION

Sentinel-2 (2017–present) · S2_NDVI_MEAN

Class	NDVI range	Label
0	no data	No data
1	< 0.15	Bare / no cover crop
2	0.15 – 0.30	Sparse / possible cover crop
3	0.30 – 0.50	Moderate / likely cover crop
4	> 0.50	Dense / confirmed cover crop

General remote sensing convention for winter vegetation interpretation

Landsat (pre-2017 & S2 fallback) · LS_NDVI_MEAN

Class	NDVI range	Label
0	no data	No data
1	< 0.321	Bare / no cover crop
2	0.321 – 0.517	Sparse / possible cover crop
3	0.517 – 0.717	Moderate / likely cover crop
4	> 0.717	Dense / confirmed cover crop

Project-derived: S2 thresholds offset by mean sensor difference (−0.2033 NDVI units)

NDTI CLASSIFICATION

Sentinel-2 (2017–present, excl. 2022) · S2_NDTI_MEAN

Class	Range	Label
1	< 0.08	Low residue / bare
2	0.08 – 0.15	Moderate residue
3	≥ 0.15	High residue / cover crop

Project-derived: empirically adjusted from Van Deventer et al. (1997) to match local Skagit distribution

VH/VV RATIO — SAR CLASSIFICATION

Sentinel-1 (2017–present) · S1_VHVV_MEAN

Class	Range	Label
1	< −12.0 dB	Bare / no vegetation
2	−12.0 – −8.0 dB	Ambiguous
3	≥ −8.0 dB	Vegetated / cover crop likely

Project-defined based on SAR backscatter behaviour in agricultural settings

CC_CONFIDENCE FLAGS — NDVI × VH/VV AGREEMENT

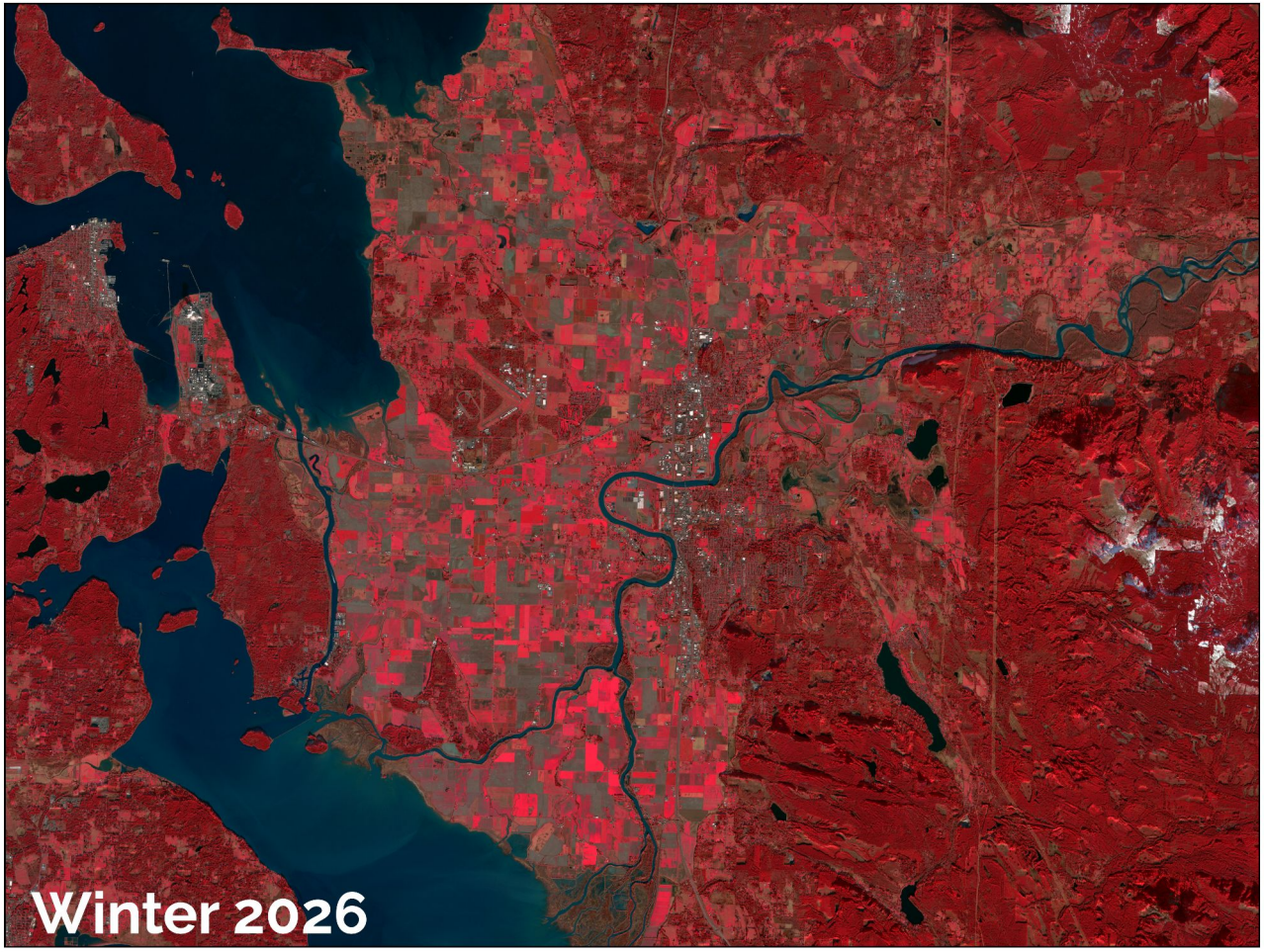
Flag	Condition	Meaning
High	NDVI class 3–4 + VH/VV ≥ −8.0 dB or NDVI class 1–2 + VH/VV ≤ −12.0 dB	NDVI and SAR agree on vegetation presence / absence
Medium	VH/VV ambiguous, missing, or pre-2017	NDVI only — no independent corroboration available
Low	NDVI class 3–4 + VH/VV ≤ −12.0 dB or NDVI class 1–2 + VH/VV ≥ −8.0 dB	NDVI and SAR clearly disagree — field review recommended
No data	CC_Class = 0	No NDVI available for classification

*Image created using Anthropic AI

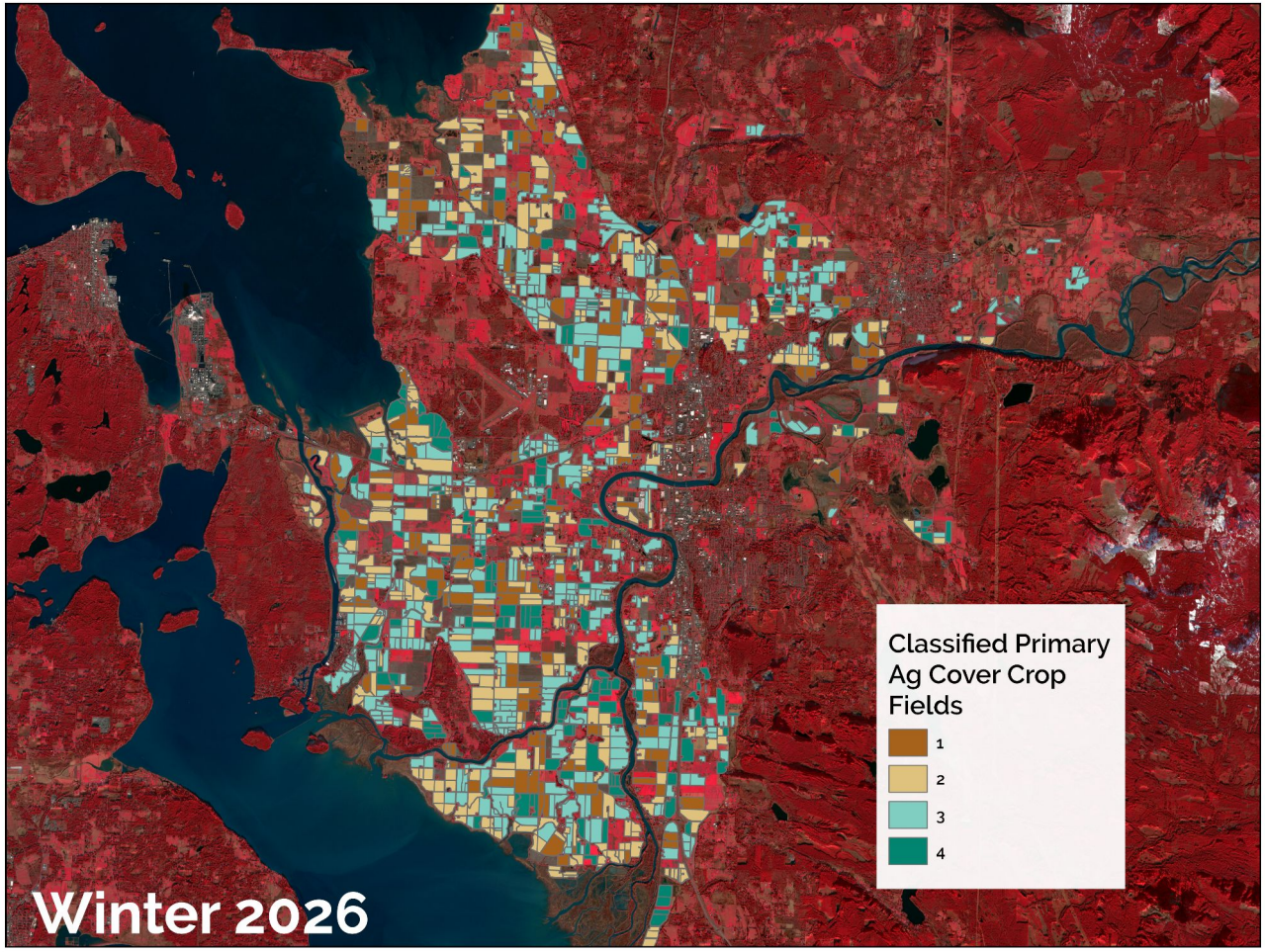
L8 Band		CW (µm)	Wavelength (lower-upper)	Bandwidth	Res. (m)		S2 Band		CW (µm)	Wavelength (min-max)	Bandwidth	Res. (m)
1	C/A	0.443	0.435 - 0.451	0.016	30	C/A	1	C/A	0.443	0.421 - 0.457	0.036	60
2	Blue	0.482	0.452 - 0.512	0.060	30	Blue	2	Blue	0.494	0.439 - 0.535	0.096	10
3	Green	0.561	0.533 - 0.590	0.057	30	Green	3	Green	0.560	0.537 - 0.582	0.045	10
4	Red	0.655	0.636 - 0.673	0.037	30	Red	4	Red	0.665	0.646 - 0.685	0.039	10
							5	VRE	0.704	0.694 - 0.714	0.020	20
							6	VRE	0.740	0.731 - 0.749	0.018	20
							7	VRE	0.781	0.768 - 0.796	0.028	20
							8	NIR	0.834	0.767 - 0.908	0.141	10
5	NIR	0.865	0.851 - 0.879	0.028	30	NIR	8a	NIR	0.864	0.848 - 0.881	0.033	20
							9	WV	0.944	0.931 - 0.958	0.027	60
9	Cirrus	1.373	1.363 - 1.384	0.020	30	Cirrus	10	Cirrus	1.375	1.338 - 1.414	0.076	60
6	SWIR	1.609	1.567 - 1.651	0.085	30	SWIR	11	SWIR	1.612	1.539 - 1.681	0.142	20
7	SWIR	2.201	2.107 - 2.294	0.187	30	SWIR	12	SWIR	2.194	2.072 - 2.312	0.240	20
8	Pan	0.590	0.503 - 0.676	0.172	15							
10	TIRS	10.895	10.60 - 11.19	0.590	100 *							
11	TIRS	12.005	11.50 - 12.51	1.010	100 *							

$$NDVI = \frac{(B08 - B04)}{(B08 - B04)}$$

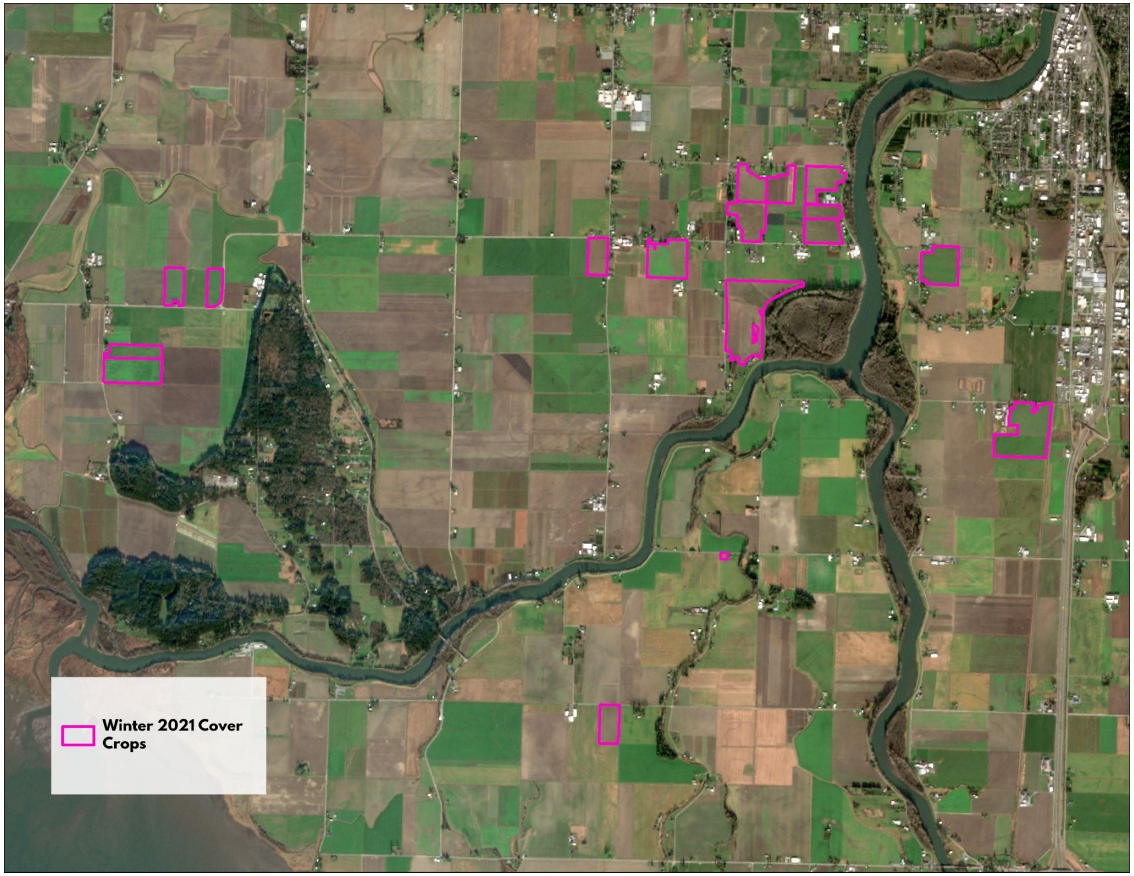
$$NDVI = \frac{(B05 - B04)}{(B05 - B04)}$$



SKAGIT CONSERVATION DISTRICT


Classified Primary Ag Cover Crop Fields
1
2
3
4
Winter 2026

Ground Truthing: Skagit CD Client Data



- Skagit CD client records
  - landowners with documented cover crop adoption
- Attempted to use as spatial validation against classified imagery

Cover Crop BMP Validation — Remote Sensing Results

Skagit Conservation District · Winter seasons 2021–2026 · n = 61 BMPs

SKAGIT CONSERVATION DISTRICT

VALIDATION RESULTS

Parcel-level method

Point-match method

Note: Inconclusive and no-data results largely reflect location ambiguity rather than confirmed absence of cover crops.

HOW MONITORING WORKS TODAY

- **Staff site visits** confirm practice implementation and record completion dates in the BMP tracking system.
- **Participant self-reporting** accounts for many plantings, with staff follow-up where possible.
- **Field locations** are recorded inconsistently — sometimes a parcel centroid, sometimes a landowner address — rather than a GPS point at the actual field.
- **Parcels often contain multiple fields,** making it difficult to link a BMP record to a specific location on the ground.

IMPROVING ACCURACY — NEXT STEPS

1. **Consistent GPS collection** at the field level — a coordinate or polygon recorded at time of practice implementation, not the parcel or address.
2. **Field-level data entry** via mobile app or ArcGIS Field Maps during staff visits and self-reporting workflows.
3. **Stronger remote sensing validation** — accurate GPS points would allow direct pixel-level NDVI and NDTI queries rather than parcel-level proximity matching.
4. **Better program reporting** to NRCS and funders on verified practice adoption, supported by spatial evidence.

Improved location data would directly strengthen SCD's ability to monitor and report on cover crop adoption over time.

Results based on Sentinel-2 NDVI · Winter seasons 2021–2026

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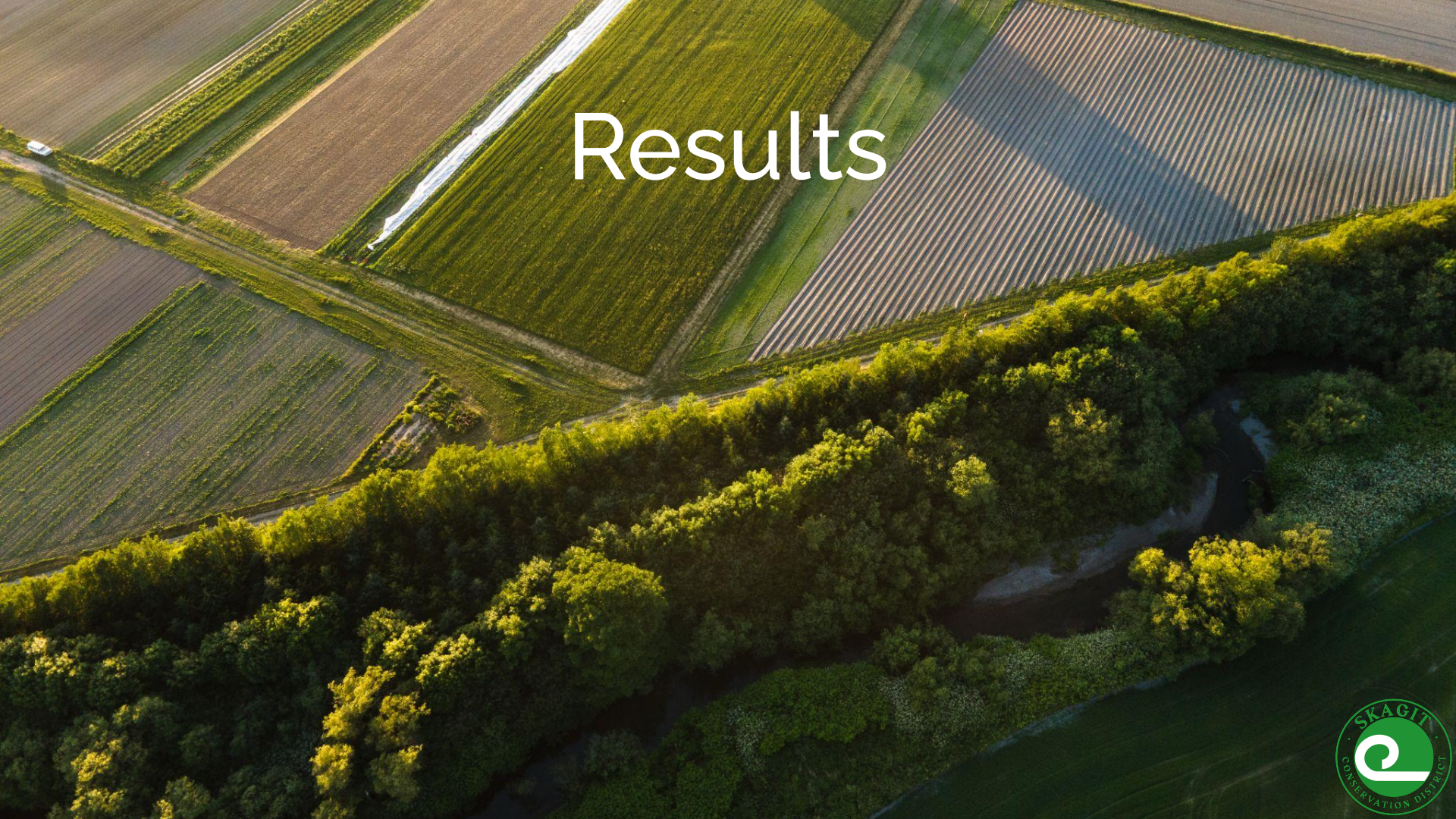
*Image created using Anthropic AI

Noted Limitations

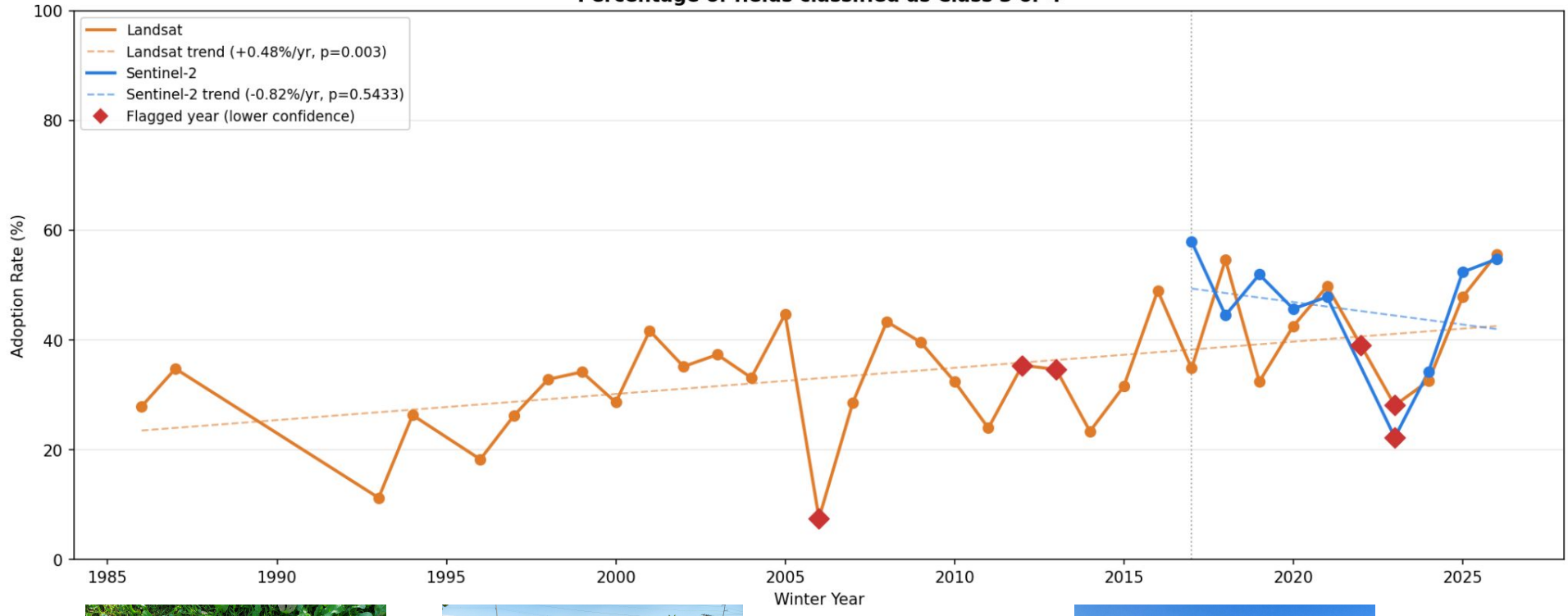
- Study area defined from WSDA 2024 layer
  - Fields converted to/from agriculture not fully captured
  - Field are regularly rotated for cash crop type (not consistently one type)
- Cloud and snow cover limit imagery availability
  - Do not have imagery for every winter
    - 1988-1992, 1995, 2022
    - 2022 mitigated with Sentinel-1 SAR integration
  - 2006 had near total data absence - looks like low adoption
- Cross sensor classification introduces uncertainty in results agreements
- Ground truthing data not reliable - actual fields not recorded

Results



NDVI

Cover Crop Adoption Rate -- PrimaryAg
Percentage of fields classified as Class 3 or 4



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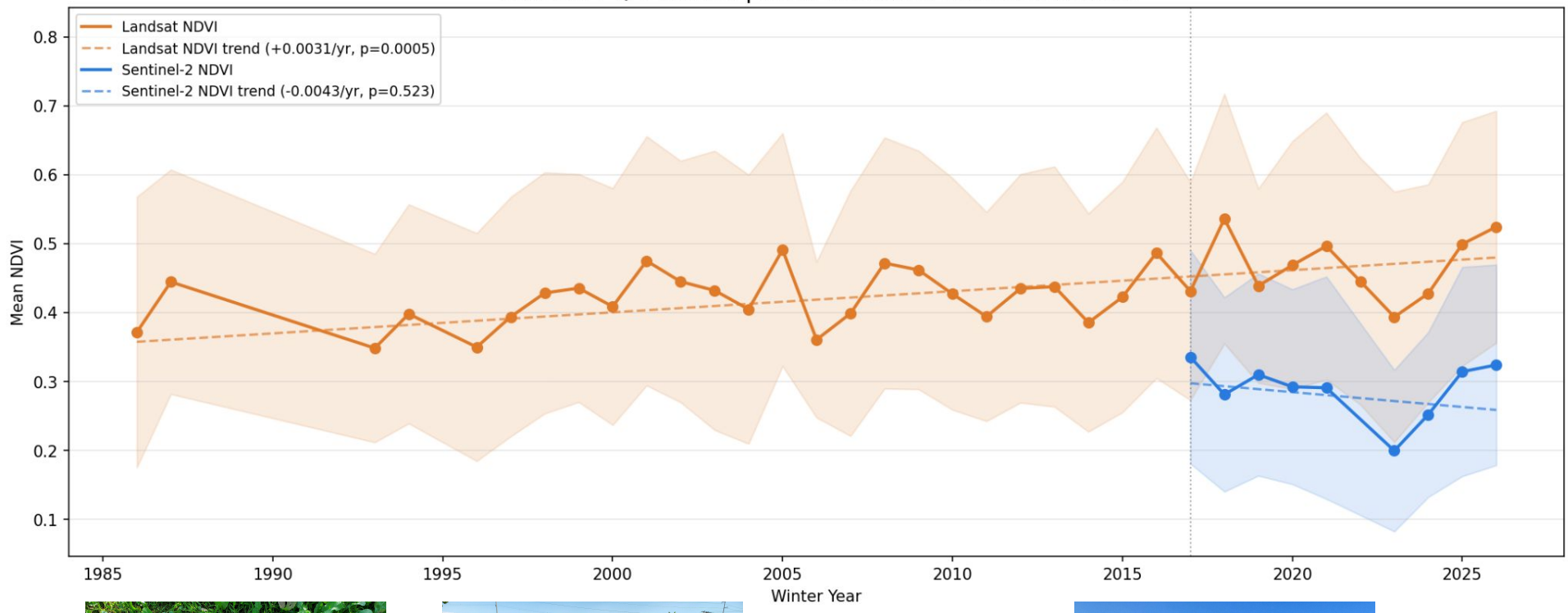
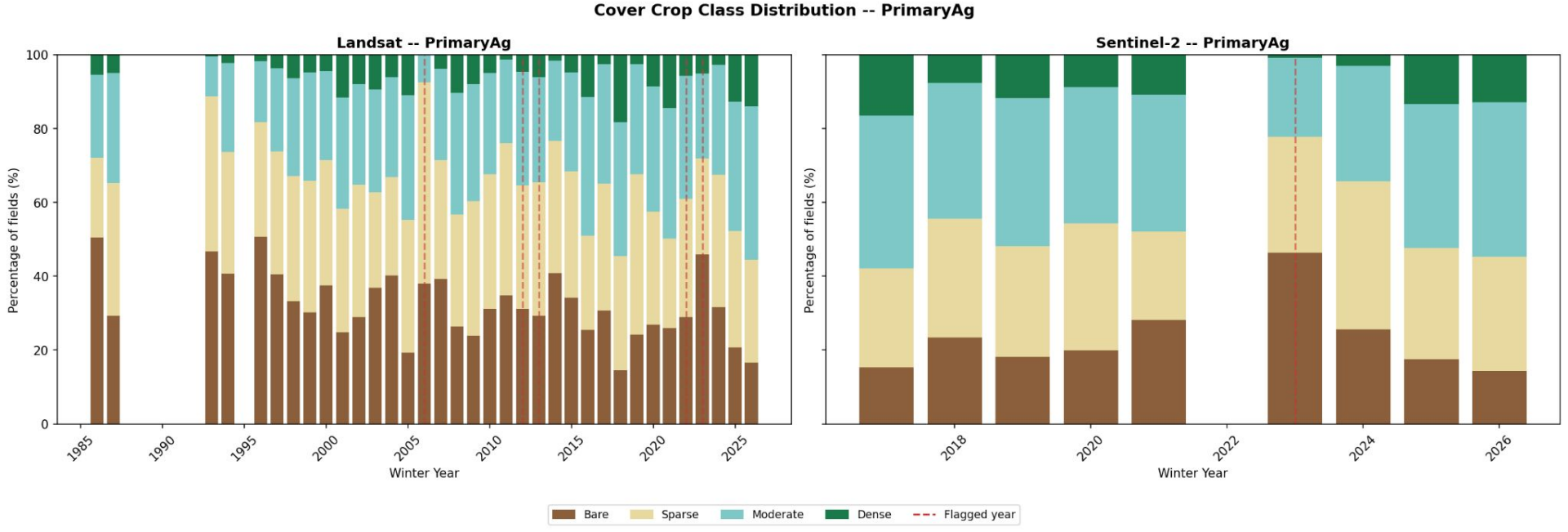
NDVI

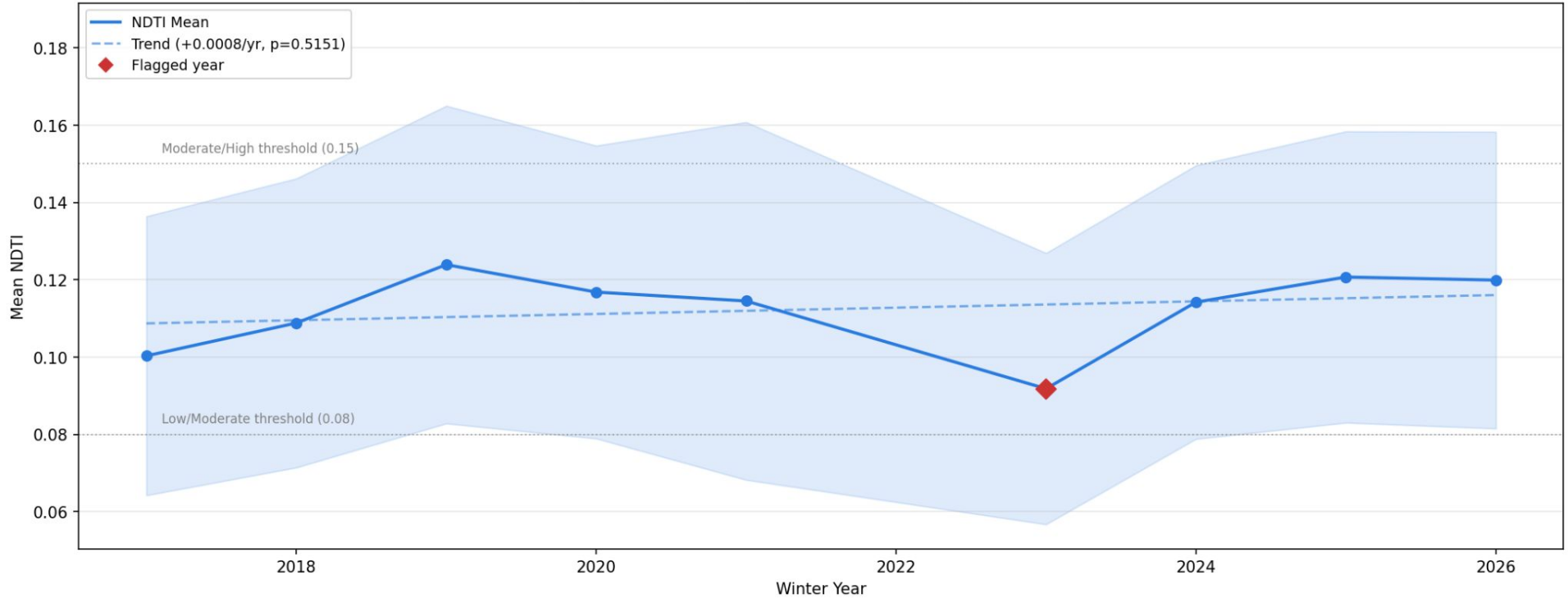

Mean NDVI Trend -- PrimaryAg
Shaded = +/-1 std dev | Trend line based on annual median
Landsat NDVI
Landsat NDVI trend (+0.0031/yr, p=0.0005)
Sentinel-2 NDVI
Sentinel-2 NDVI trend (-0.0043/yr, p=0.523)
Mean NDVI
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
1985
1990
1995
2000
2005
2010
2015
2020
2025
Winter Year

NDVI


Cover Crop Class Distribution -- PrimaryAg
Landsat -- PrimaryAg
Sentinel-2 -- PrimaryAg
Percentage of fields (%)
Winter Year
Bare
Sparse
Moderate
Dense
Flagged year

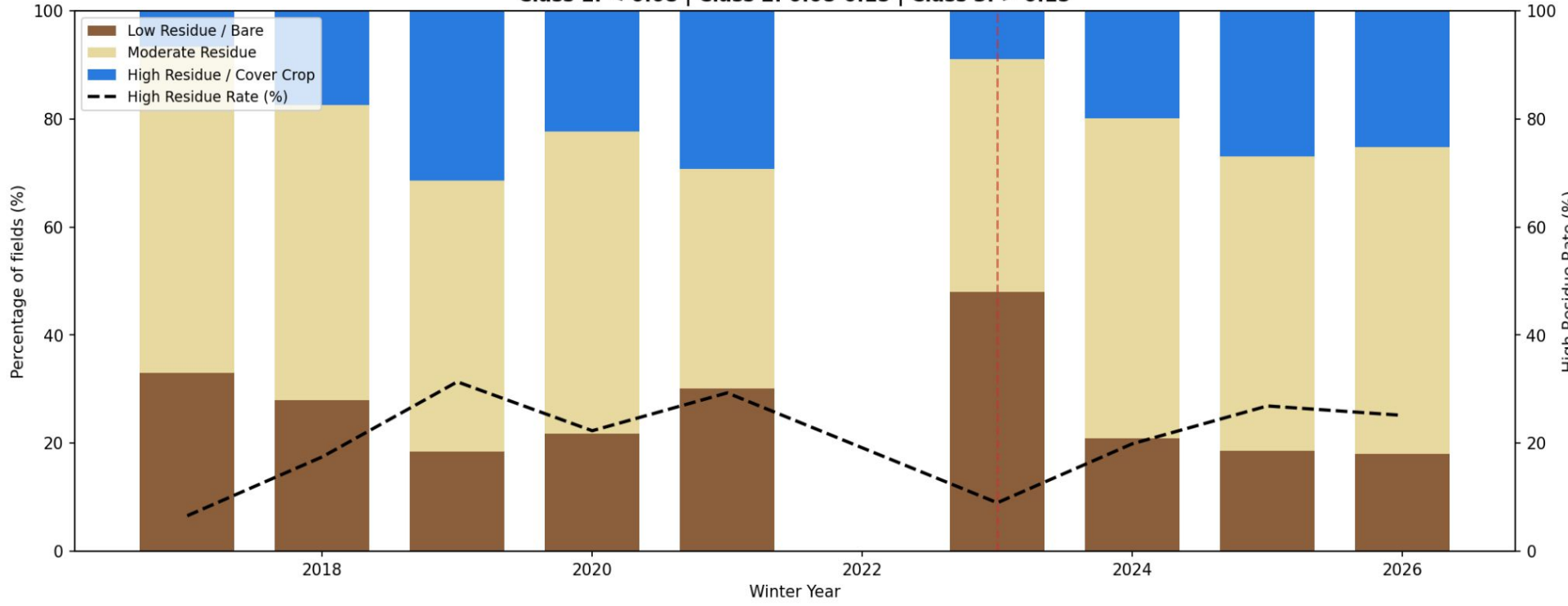
NDTI

NDTI Mean Trend -- PrimaryAg
Sentinel-2 only (2017-present, excl. Winter 2022) | Shaded = +/-1 std dev



NDTI

NDTI Class Distribution -- PrimaryAg
Sentinel-2 only (2017-present, excl. Winter 2022)
Class 1: < 0.08 | Class 2: 0.08-0.15 | Class 3: > 0.15



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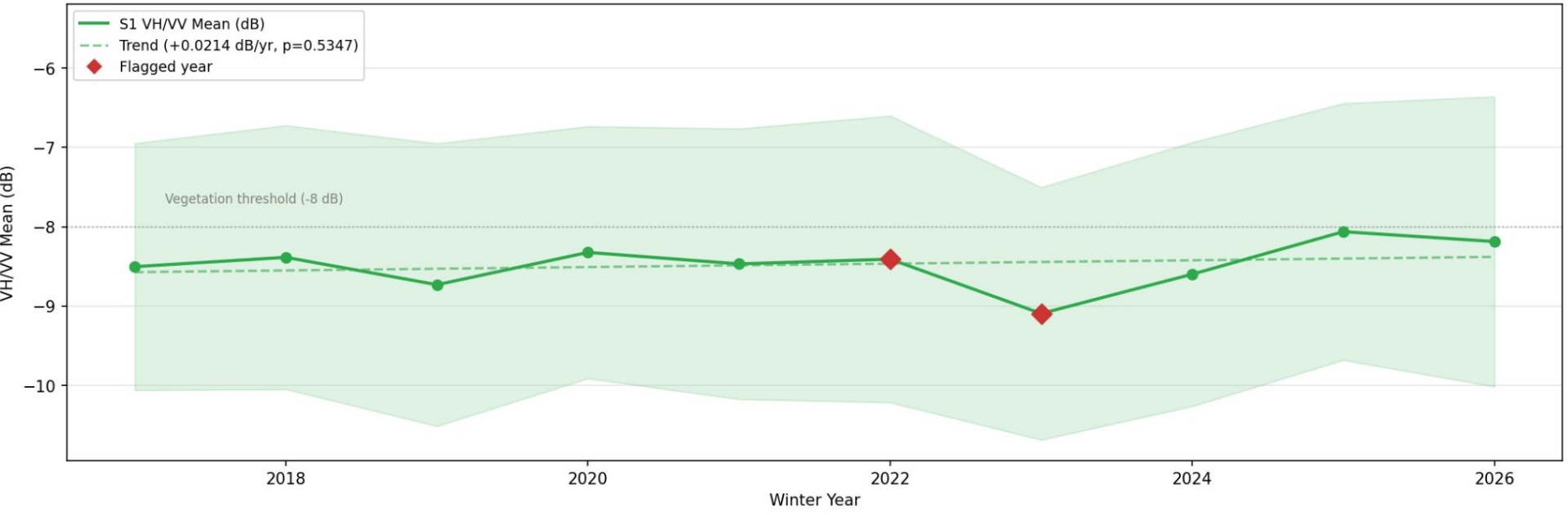
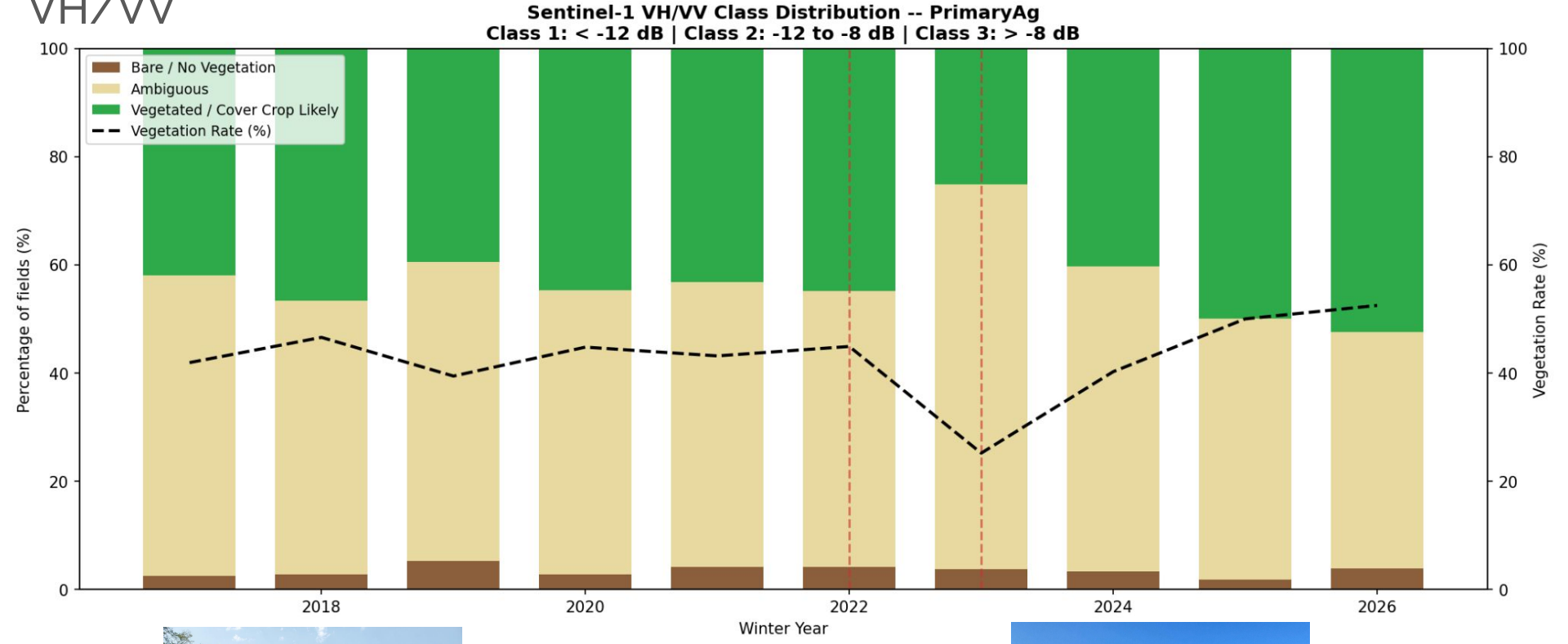
VH/VV

Sentinel-1 VH/VV Mean Trend -- PrimaryAg
Shaded = +/-1 std dev | Grey lines = confidence thresholds



Bare soil threshold (-12 dB)

VH/VV


Sentinel-1 VH/VV Class Distribution -- PrimaryAg
Class 1: < -12 dB | Class 2: -12 to -8 dB | Class 3: > -8 dB
Bare / No Vegetation
Ambiguous
Vegetated / Cover Crop Likely
Vegetation Rate (%)
Percentage of fields (%)
Vegetation Rate (%)
Winter Year
0
20
40
60
80
100
2018
2020
2022
2024
2026

Findings

- Significant Cover Crop adoption over the last 40 years (Landsat)
  - Not a significant change in the last 10 years according to Sentinels 1 and 2
- Year 2023 was a particularly low Cover Crop year across all sensors and variables

A Note on the Year 2023 Trend

- Fall 2022 was a Whipsaw
  - Extremely ***warm*** **October** (warmest on record in WA) to an unseasonably ***cold*** **November** (5th coldest on record in WA)
- Wildfire smoke remained in Skagit Valley through mid October
  - Air quality was low
  - Cover crop planting would occur in Sept - October

Credit: Modis - October 19, 2022

Possible Future Applications

- With more reliable cover crop adopters data
  - Track real time cover crop use
- Coordinate with Skagit County & Washington Dept of Ecology to compare stream pollution and runoff to years with higher or lower Cover Crop use

Next Steps

Outreach!


SKAGIT
CONSERVATION DISTRICT
SOIL • WATER • WOODLAND
THANK YOU!