Characterizing spatial and temporal patterns of conductivity in freshwater tributaries within the Chesapeake Bay watershed

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Integrated Trends Analysis Team (ITAT)
February 28, 2024

Term definitions

Salinity: concentration of salt ions dissolved in water

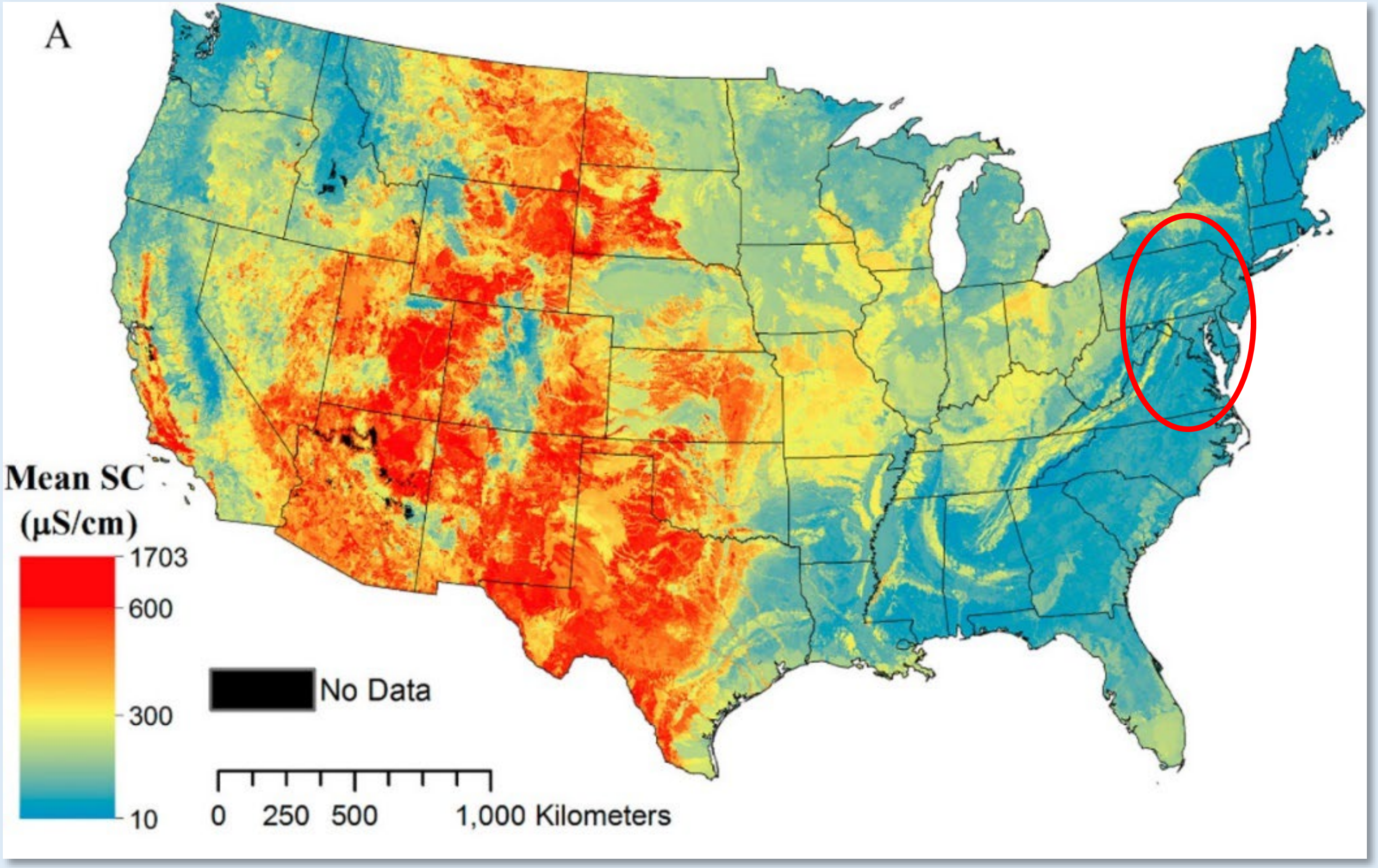
Freshwater salinization: increased concentrations of salt ions in naturally low saline waters

Conductivity: electrical conductance of water (increases with salinity)

Specific conductance (SC): conductivity of 1 cm^3 water at 25^oC

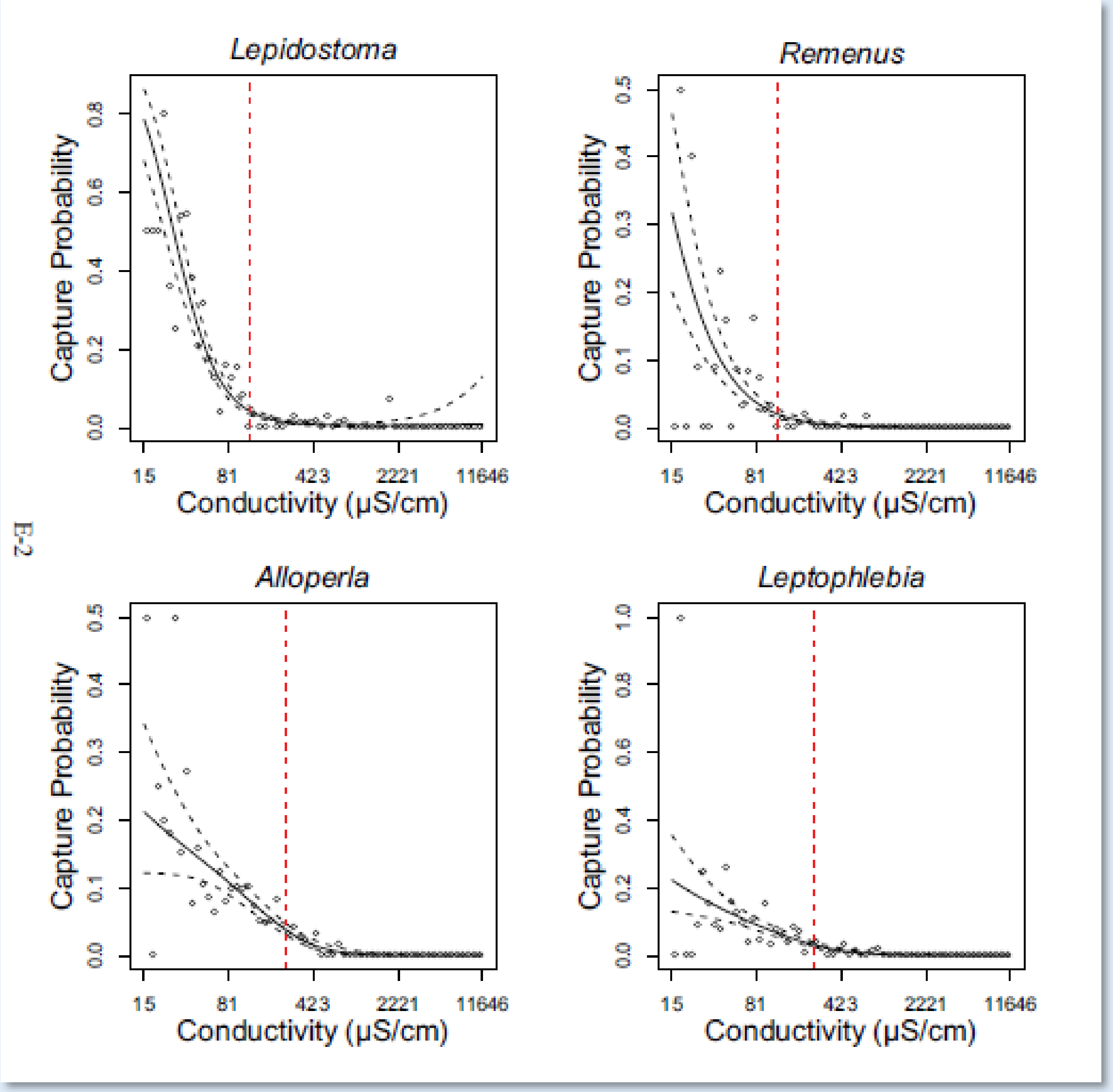
SC in the CB watershed

- Usually 20-400 µS/cm
- Natural sources
  - Carbonate lithology
  - Seawater aerosol
  - Precipitation/deposition
- Anthropogenic sources
  - Deicer applications
  - Material weathering
  - Agricultural land use
  - Resource extraction
  - Point source discharge



Olson, J. and S. Cormier. 2019. Modeling Spatial and Temporal Variation in Natural Background Specific Conductivity. *Environ. Science and Technology.* 53, 4316−4325. https://pubs.acs.org/doi/10.1021/acs.est.8b06777

Effects of freshwater salinization



- Elevated ions can be an ecological stressor to aquatic organisms
- Excess ions can mobilize metals
- Influences biogeochemical cycling
- Can make other contaminants more toxic (6PPD, a synthetic tire compound)
- Human health implications
    - Corrosivity of water infrastructure
    - Water supplies meeting sodium-restricted diet thresholds

Clements and Kotalik, 2016. Effects of major ions on natural benthic communities: an experimental assessment of the US Environmental Protection Agency aquatic life benchmark for conductivity. Freshwater Sci. 2016, 35, 126−138. https://www.journals.uchicago.edu/doi/epdf/10.1086/685085

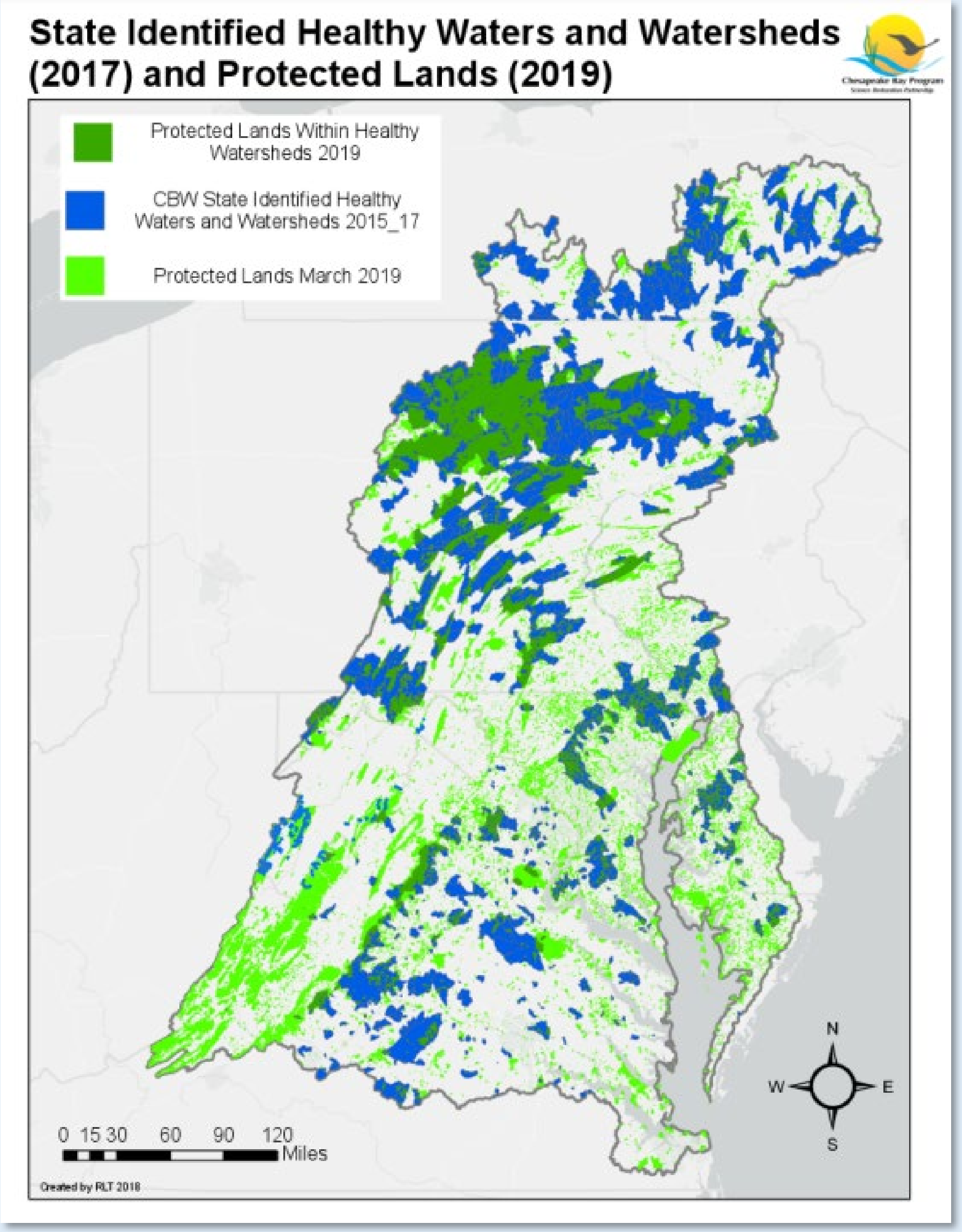
Regional stakeholder needs

Healthy Watersheds Goal Implementation Team

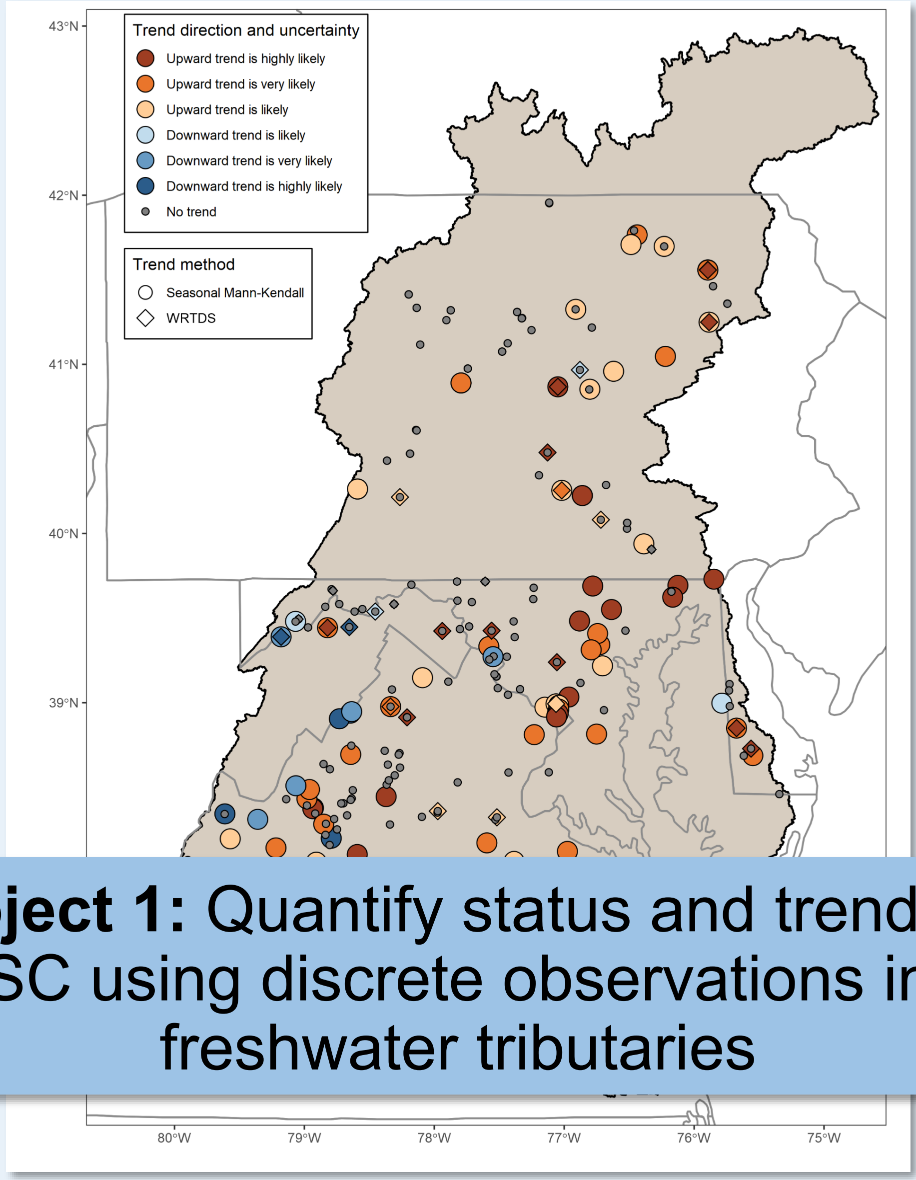
- Goal is to “is to maintain local watersheds at optimal health across a range of landscape contexts”
- More information on in-stream conditions is needed to assess healthy watershed status and determine vulnerability

Stream Health Workgroup

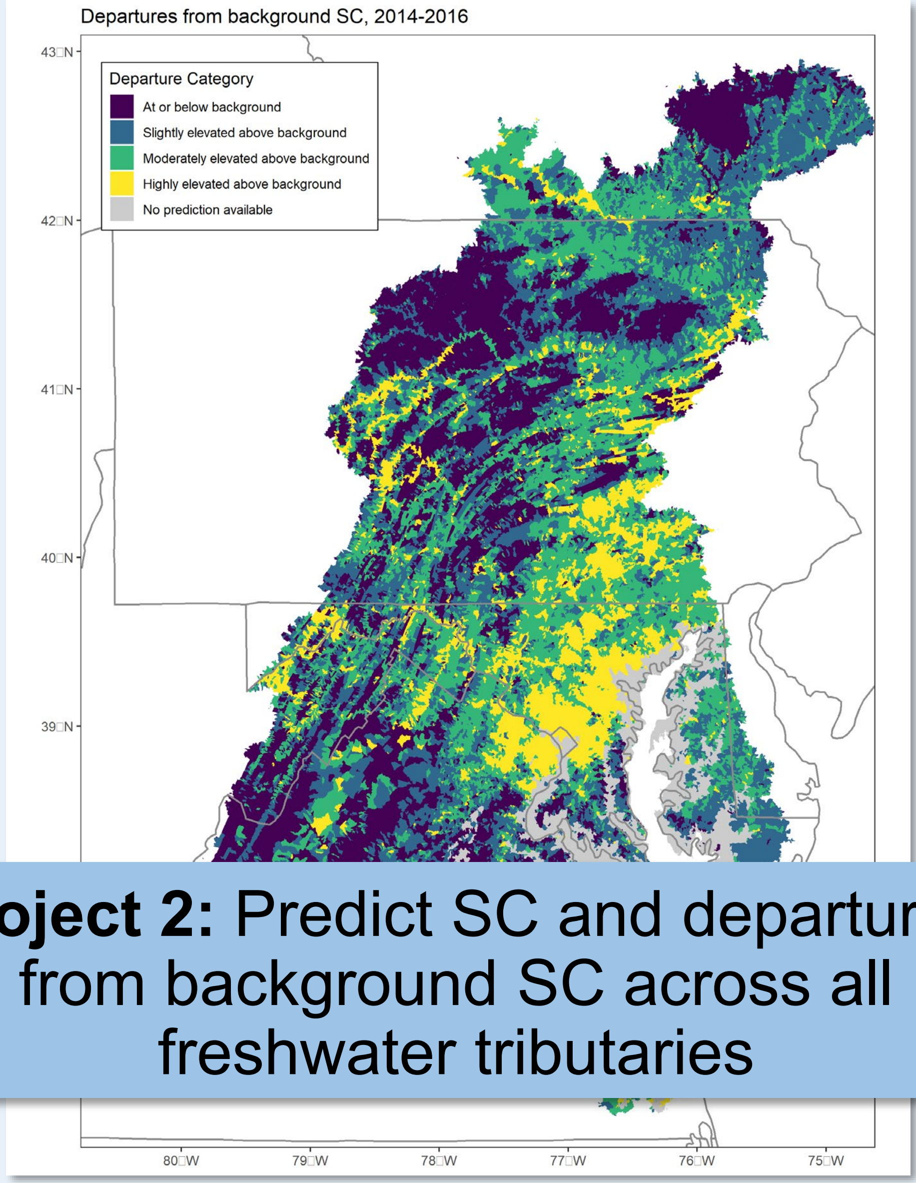
- Supporting CBP goal to improve biological conditions in 10% of stream reaches across the watershed
- Need information on what in-stream stressors may be impairing stream health



Ongoing regional USGS projects on freshwater salinization



Project 1: Quantify status and trends in SC using discrete observations in freshwater tributaries

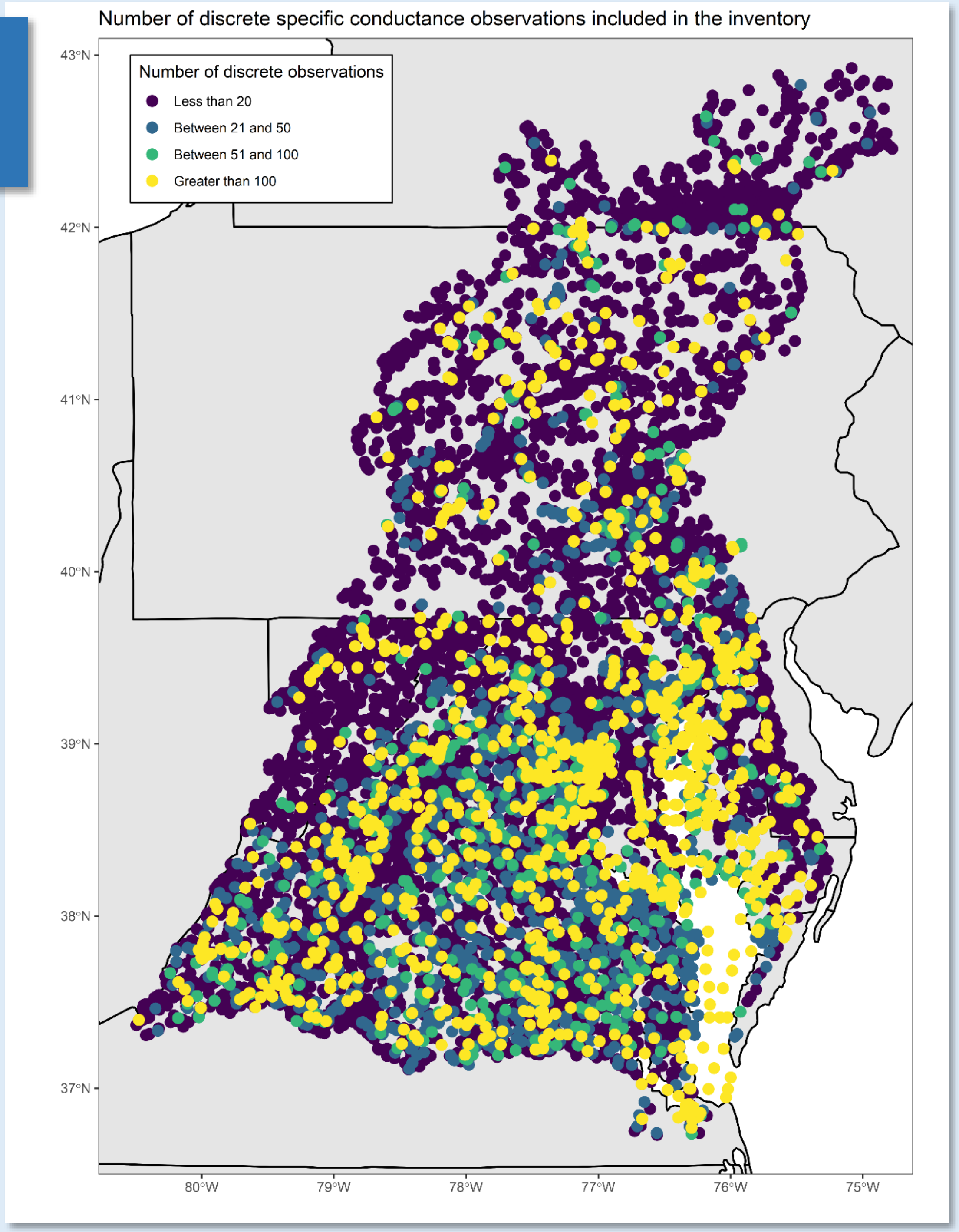


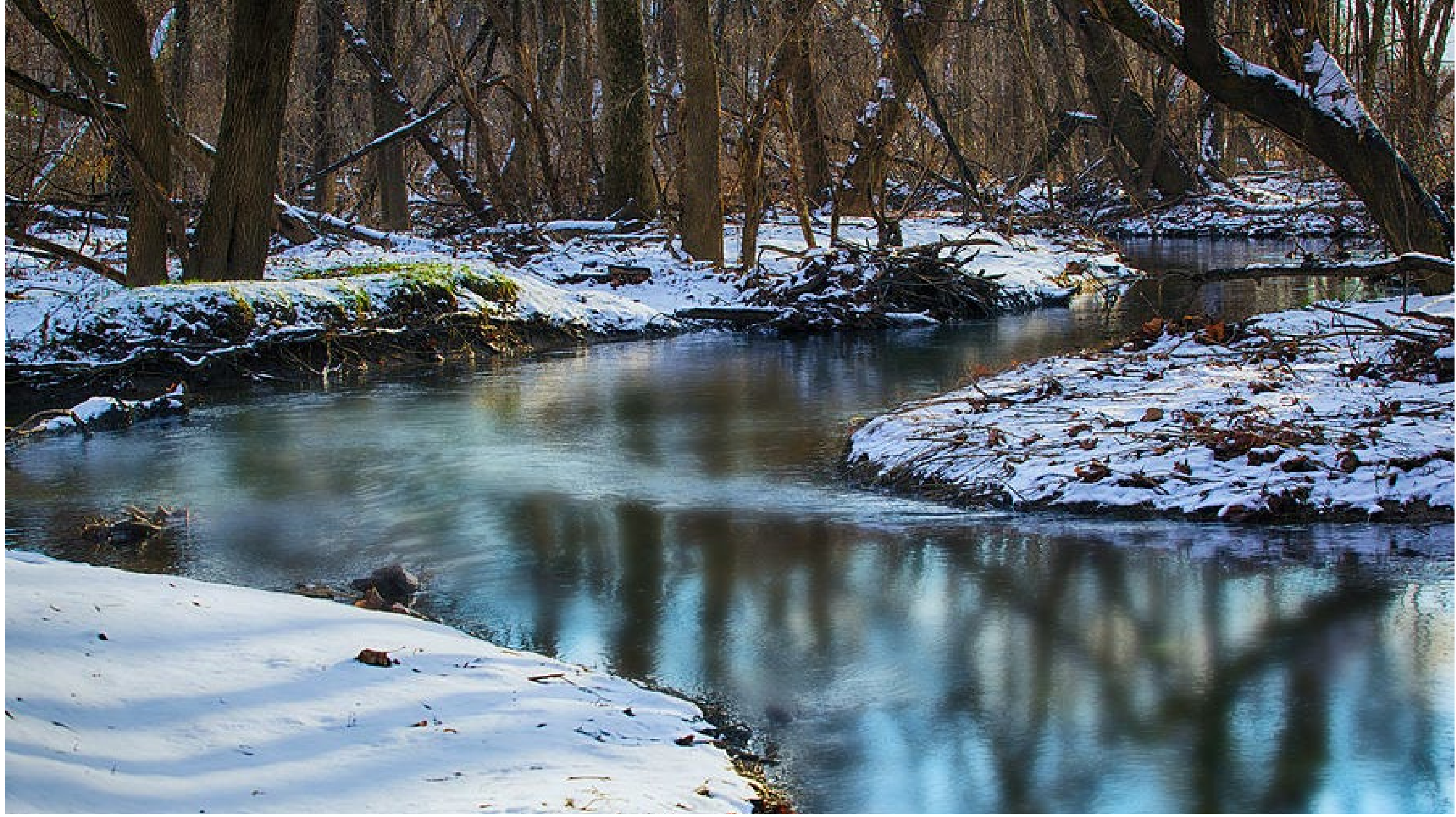
Project 2: Predict SC and departures from background SC across all freshwater tributaries

SC inventory for CB watershed

- Retrieved SC data National Water Quality Portal and USGS NWIS
- 1.2+ million discrete obs at 16,900+ sites
- 89 sites with continuous SC
- Latest data pull: July 2022
- Dataset clean up and unit harmonization
  - QA/QC samples removed
  - Surface water samples retained
  - Units harmonized to µS/cm
  - Database screened for duplicate entries

Fanelli, R.M., Sekellick, A.J., and Hamilton, W.B., 2023, Compilation of multi-agency specific conductance observations for streams within the Chesapeake Bay watershed, U.S. Geological Survey data release, https://doi.org/10.5066/P98O2HQJ.





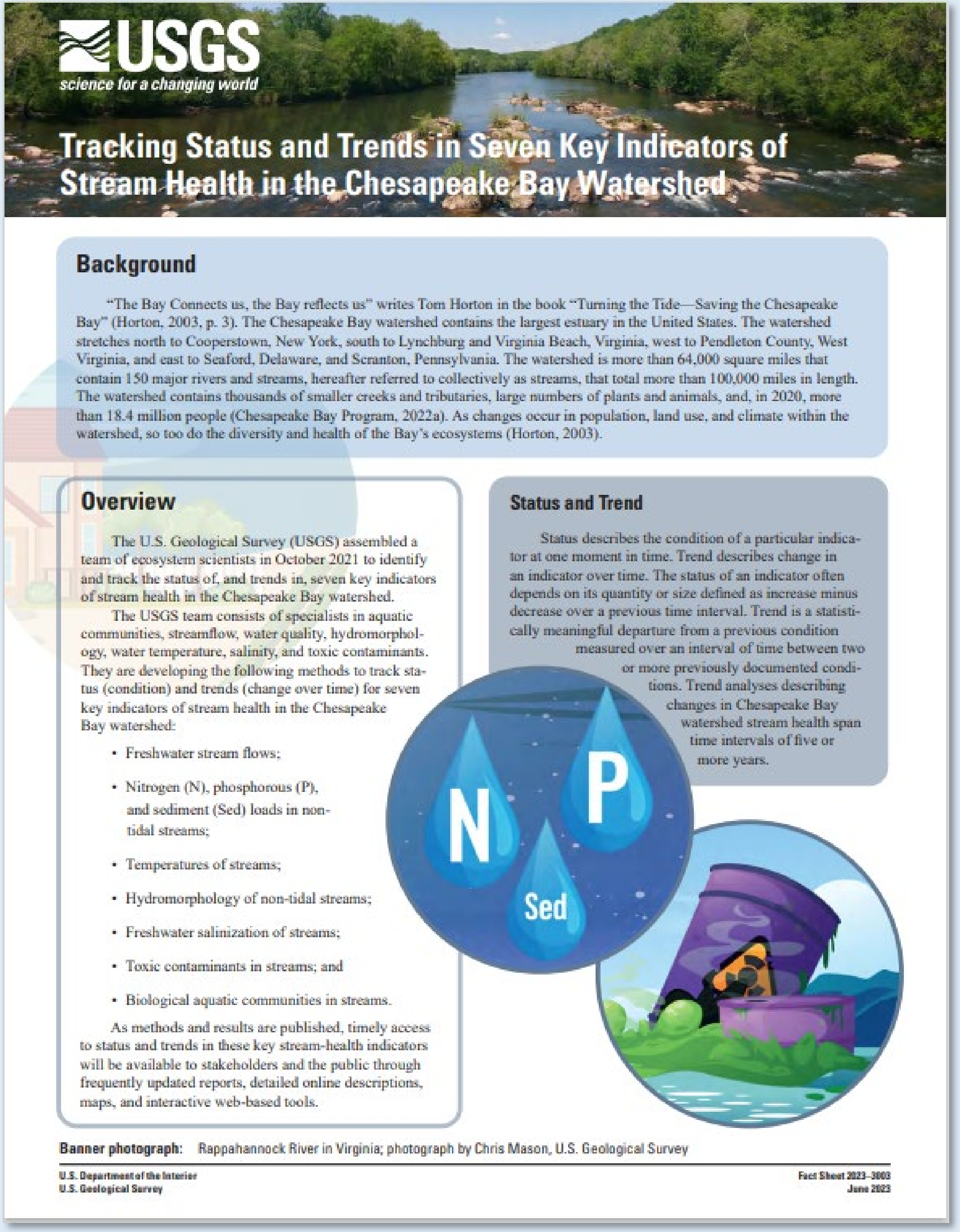
Project 1: Quantify status and trends in SC using discrete observations in freshwater tributaries

Rosemary Fanelli, SAWSC, U.S. Geological Survey
Kaitlyn Elliott, SAWSC, U.S. Geological Survey
(plus many others from the USGS)

CB status and trends

- Multi-year effort to quantify status and trends for seven indicators of **stream health**
  - Biological endpoints (Lindsey Boyle)
  - Physical habitat (Matthew Cashman)
  - Stream temperature (John Clune
  - Nutrients and sediment (Chris Mason)
  - **Salinity**
  - Flow (Sam Austin)
  - Toxic contaminants (Trevor Needham)
- Initial product: USGS SIR outlining methods and results for status and trends

Austin, S.H., Cashman, M.J., Clune, J., Colgin, J.E., Fanelli, R.M., Krause, K.P., Majcher, E.H., Maloney, K.O., Mason, C.A., Moyer, D.L., and Zimmerman, T.M., 2023, Tracking status and trends in seven key indicators of stream health in the Chesapeake Bay watershed: U.S. Geological Survey Fact Sheet 2023–3003, 6 p., https://doi.org/10.3133/fs20233003


USGS science for a changing world

Tracking Status and Trends in Seven Key Indicators of Stream Health in the Chesapeake Bay Watershed

Background

"The Bay Connects us, the Bay reflects us" writes Tom Horton in the book "Turning the Tide—Saving the Chesapeake Bay" (Horton, 2003, p. 3). The Chesapeake Bay watershed contains the largest estuary in the United States. The watershed stretches north to Cooperstown, New York, south to Lynchburg and Virginia Beach, Virginia, west to Pendleton County, West Virginia, and east to Seaford, Delaware, and Scranton, Pennsylvania. The watershed is more than 64,000 square miles that contain 150 major rivers and streams, hereafter referred to collectively as streams, that total more than 100,000 miles in length. The watershed contains thousands of smaller creeks and tributaries, large numbers of plants and animals, and, in 2020, more than 18.4 million people (Chesapeake Bay Program, 2022a). As changes occur in population, land use, and climate within the watershed, so too do the diversity and health of the Bay's ecosystems (Horton, 2003).

Overview

The U.S. Geological Survey (USGS) assembled a team of ecosystem scientists in October 2021 to identify and track the status of, and trends in, seven key indicators of stream health in the Chesapeake Bay watershed.

The USGS team consists of specialists in aquatic communities, streamflow, water quality, hydromorphology, water temperature, salinity, and toxic contaminants. They are developing the following methods to track status (condition) and trends (change over time) for seven key indicators of stream health in the Chesapeake Bay watershed:

- Freshwater stream flows;
- Nitrogen (N), phosphorous (P), and sediment (Sed) loads in non-tidal streams;
- Temperatures of streams;
- Hydromorphology of non-tidal streams;
- Freshwater salinization of streams;
- Toxic contaminants in streams; and
- Biological aquatic communities in streams.

As methods and results are published, timely access to status and trends in these key stream-health indicators will be available to stakeholders and the public through frequently updated reports, detailed online descriptions, maps, and interactive web-based tools.

Status and Trend

Status describes the condition of a particular indicator at one moment in time. Trend describes change in an indicator over time. The status of an indicator often depends on its quantity or size defined as increase minus decrease over a previous time interval. Trend is a statistically meaningful departure from a previous condition measured over an interval of time between two or more previously documented conditions. Trend analyses describing changes in Chesapeake Bay watershed stream health span time intervals of five or more years.

N P Sed

Banner photograph: Rappahannock River in Virginia; photograph by Chris Mason, U.S. Geological Survey

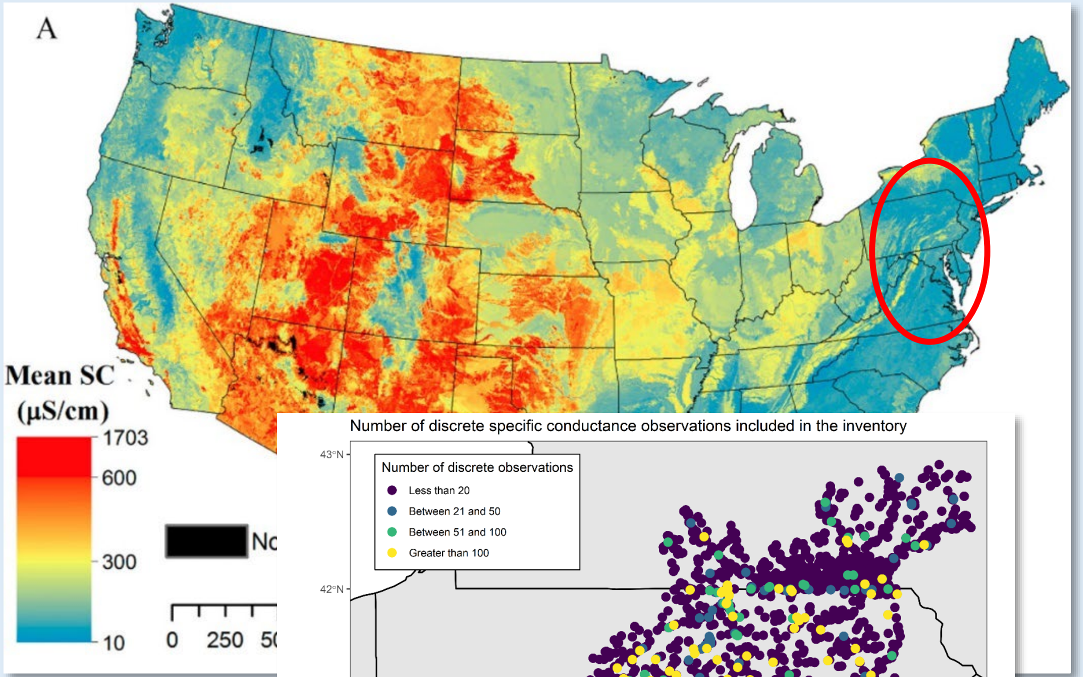
U.S. Department of the Interior
U.S. Geological Survey

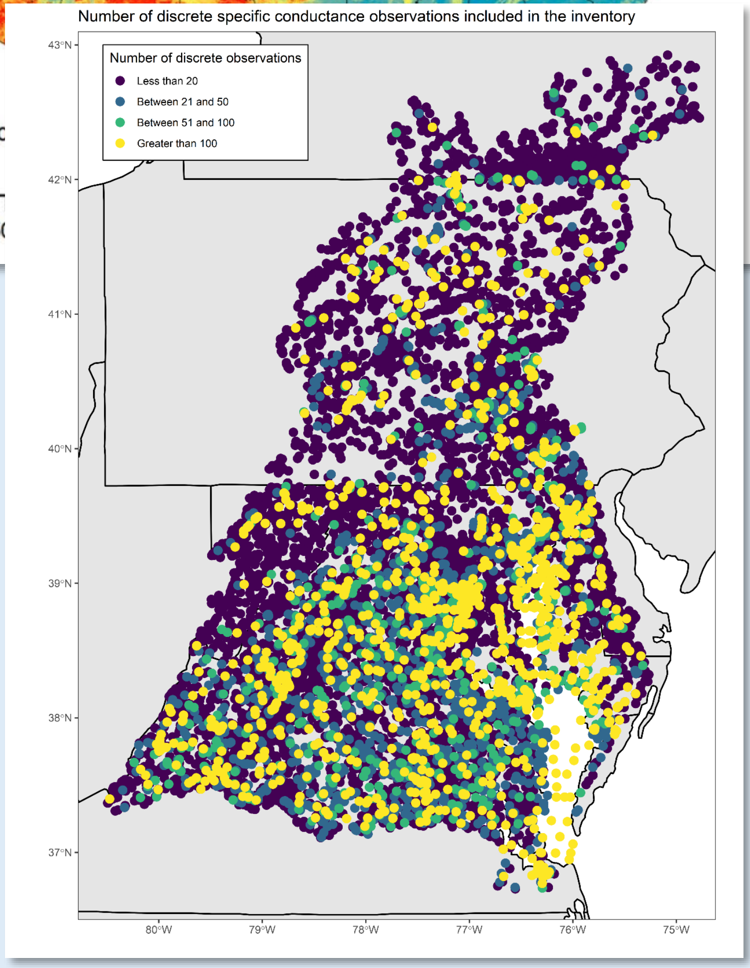
Fact Sheet 2023–3003
June 2023

Computing SC status

- The “status” of all seven indicators was characterized using the most recent data available (usually 2016-2020)
- SC status = 3-year median SC for years 2015-2017
- Sites with at least one sample per quarter for the 10-year trend window (2008-2017)
- Compared to SC background dataset
- Departures from background SC
  - At or below background SC
  - 1-2 times the background SC
  - 2-3 times the background SC
  - Greater than 3 times the background SC

Olson, J. and S. Cormier. 2019. Modeling Spatial and Temporal Variation in Natural Background Specific Conductivity. *Environ. Science and Technology.* 53, 4316−4325. https://pubs.acs.org/doi/10.1021/acs.est.8b06777

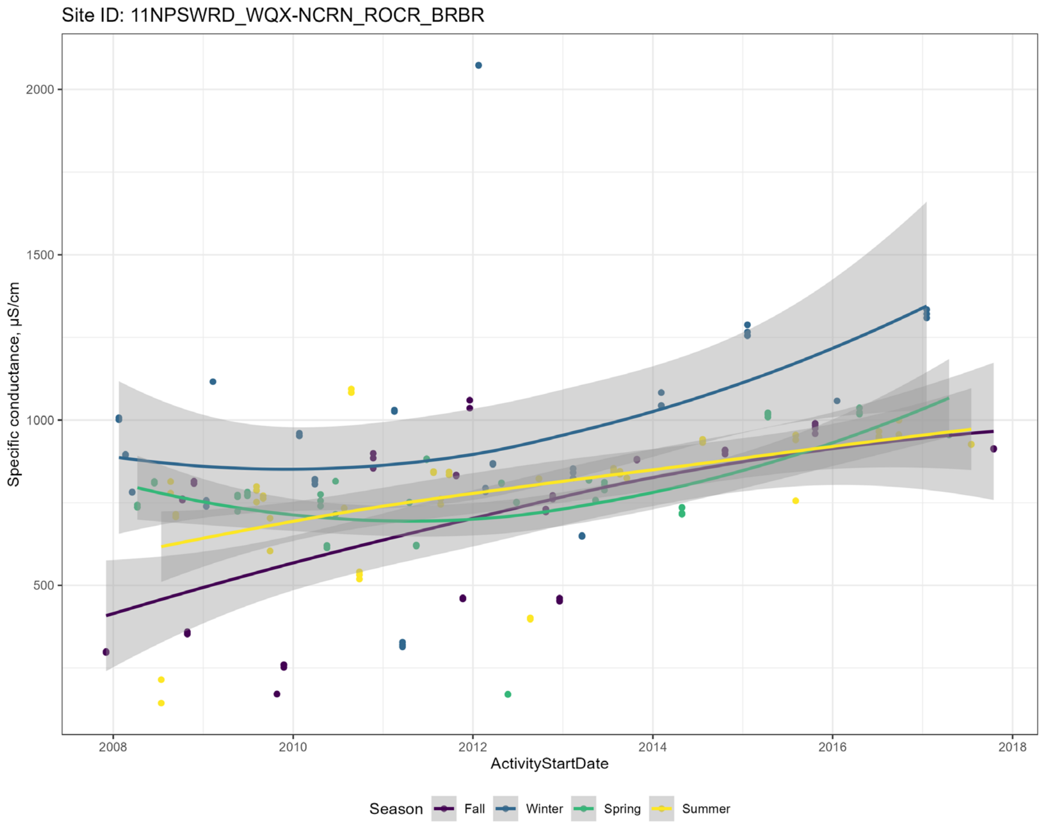




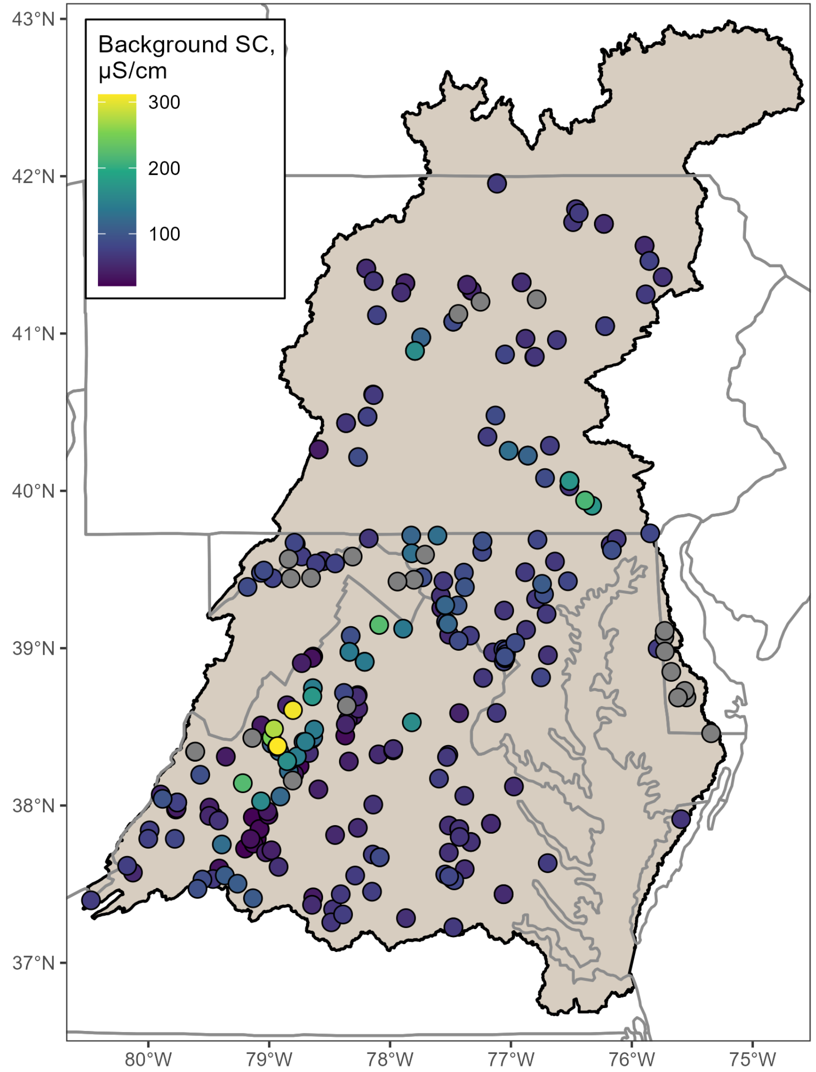
Computing SC trends

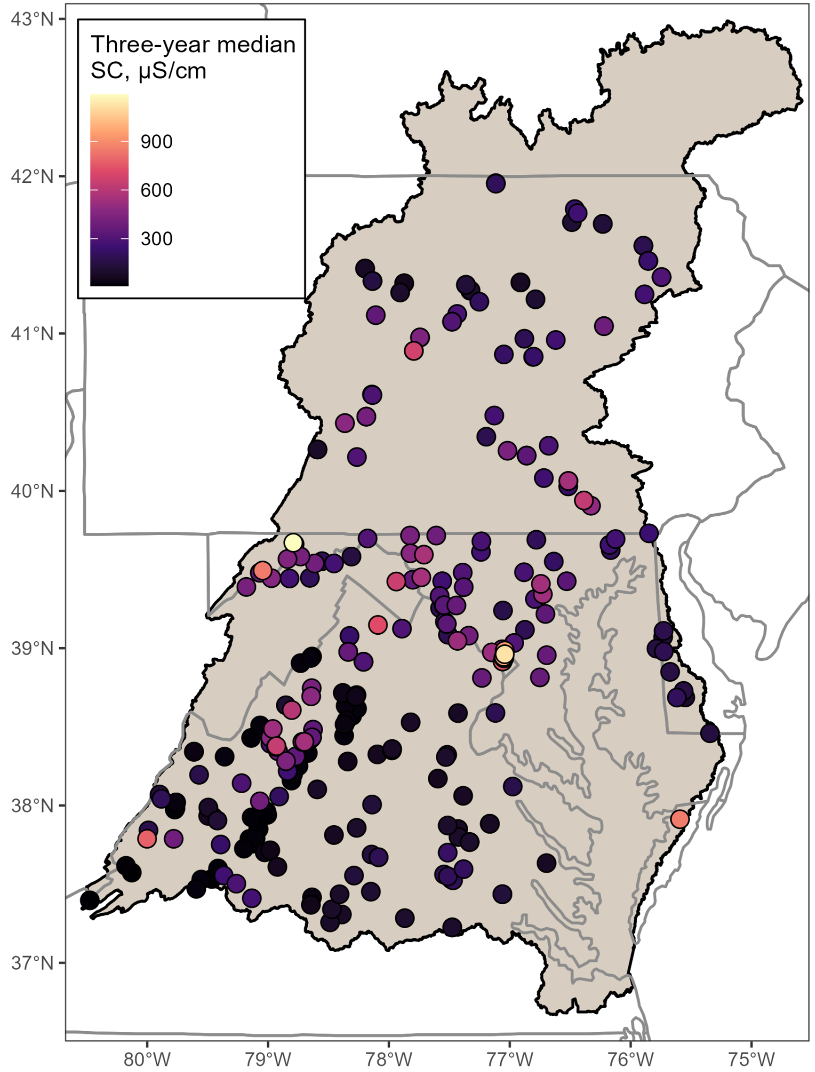
- SC trend time period: 2008-2017
- Approach 1: WRTDS
  - Accounts for interannual flow variability
  - Requires discharge record
  - SC data criteria: three samples per season for each of the 10 years in trend period
  - 35 sites qualified for WRTDS
- Approach 2: Seasonal Mann-Kendall
  - Does not require streamflow records
  - SC data criteria: one sample per season for each of the 10 years in trend period
  - 278 sites qualified for SMK
  - Defined criteria for characterizing trend significance and uncertainty

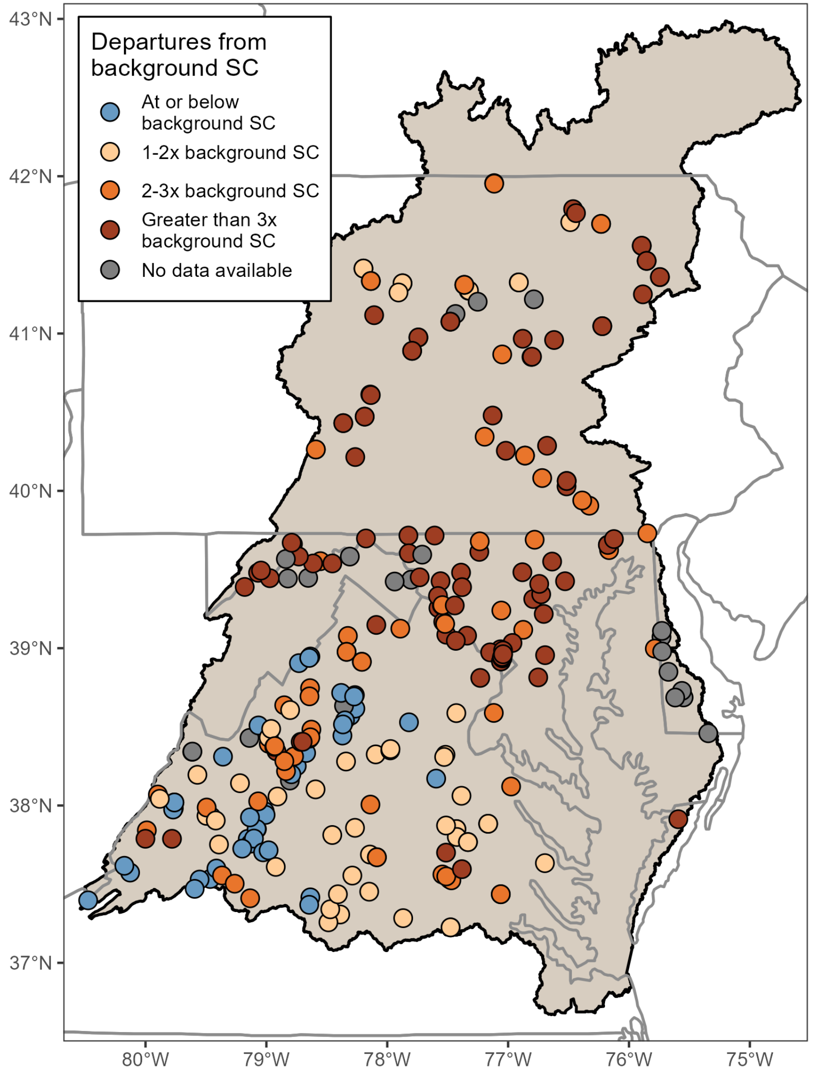
P-value from Seasonal Mann-Kendall test	Theil-sen Slope estimate	Trend category
> 0.2	NA	No trend
< 0.2 and >= 0.1	Greater than zero	Upward trend is likely
< 0.1 and >= 0.05	Greater than zero	Upward trend is very likely
< 0.05	Greater than zero	Upward trend is highly likely
< 0.2 and >= 0.1	Less than zero	Downward trend is likely
< 0.1 and >= 0.05	Less than zero	Downward trend is very likely
< 0.05	Less than zero	Downward trend is highly likely



Results: SC status







Results: SC trends

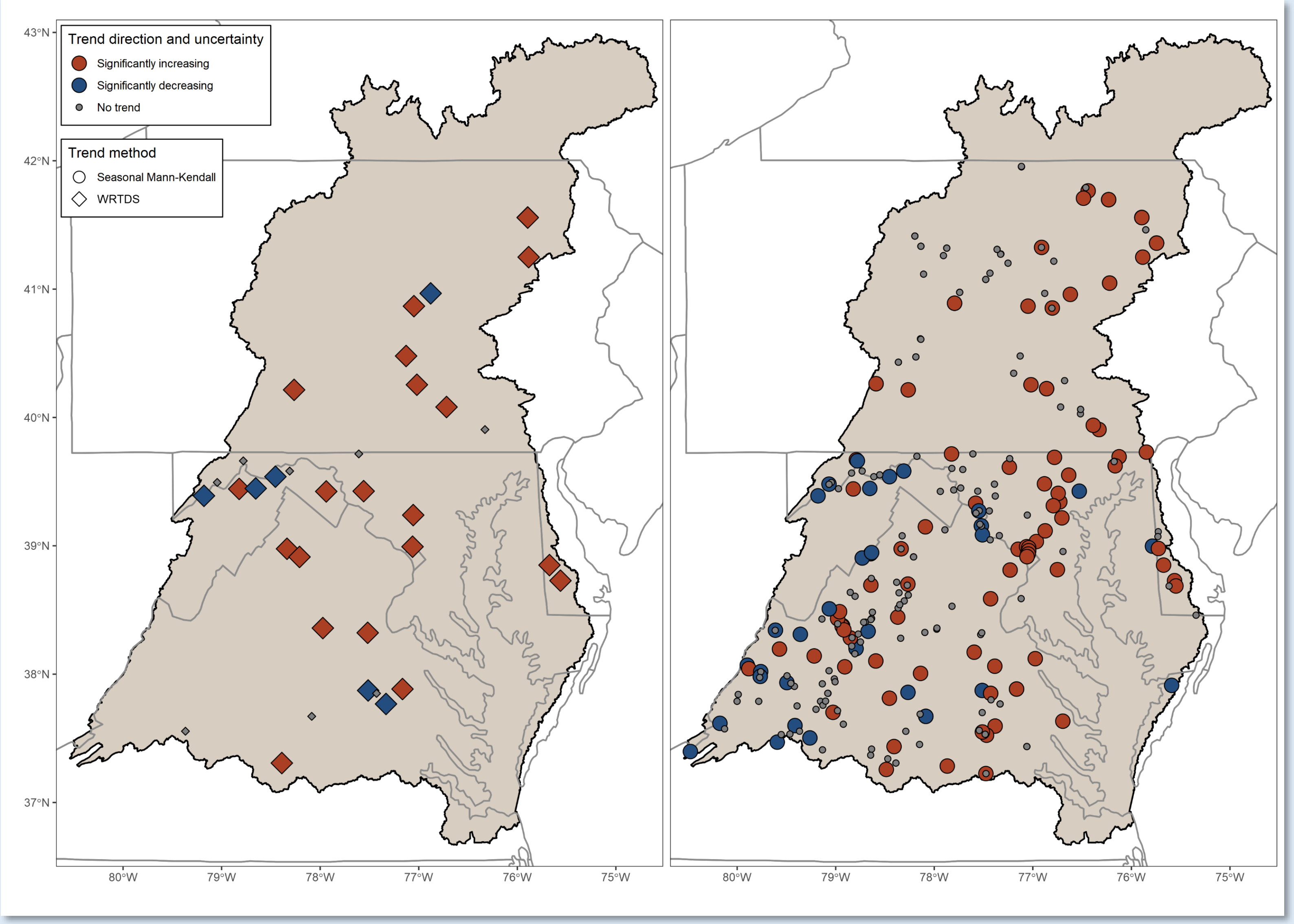
<u>WRTDS (35 sites)</u>

- 60% (21 sites) had inc. trends
- 23% (8 sites) had no trend
- 18% (6 sites) had dec. trends

<u>SMK (278 sites)</u>

- 55% (152 sites) had no trend
- 33% (92 sites) had inc. trends
- 12% (34 sites) had dec. trends

WRTDS **Seasonal Mann-Kendall**



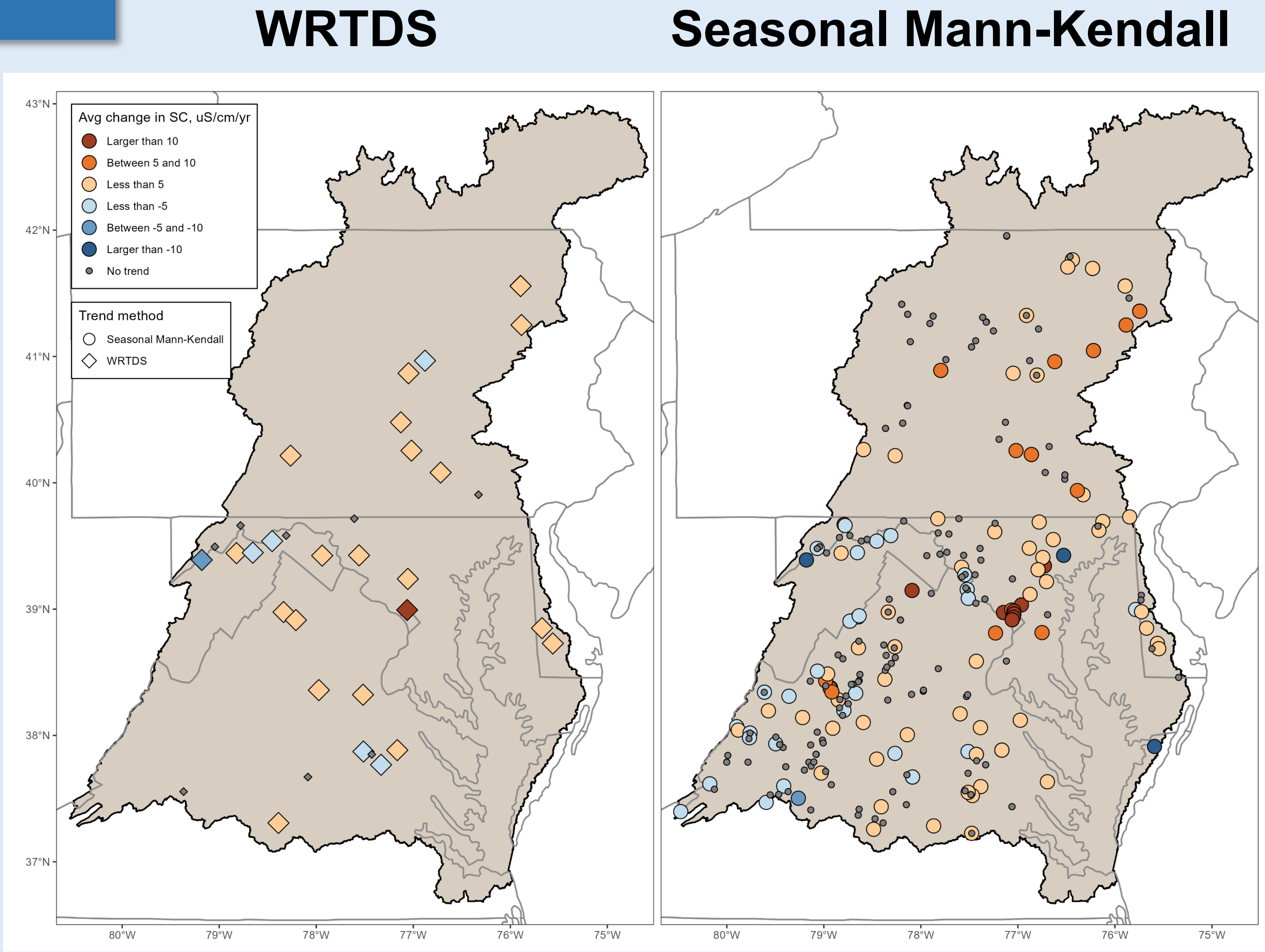
Results: SC trends

WRTDS

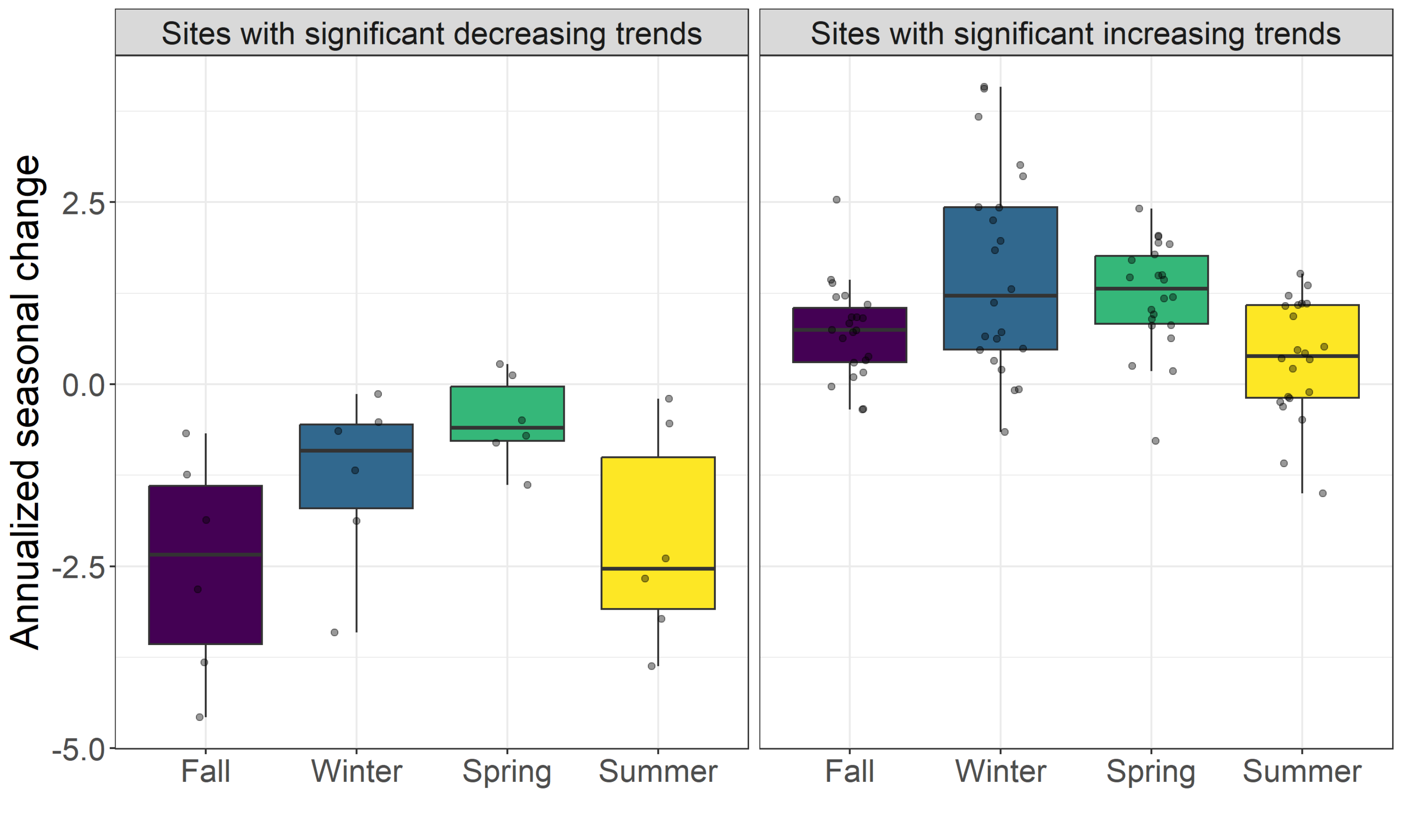
- 95% of upward trending sites (20 sites) had small rates of change (< +5 µS/cm/yr)
- 83% of the downward trending sites (5) had small rates of change (< -5 µS/cm/yr)

Seasonal Mann-Kendall

- 66% of upward trending sites (51 sites) had small rates of change (< +5 µS/cm/yr)
- 13% of upward trending sites (12) had large rates of change rates of change (> +10 µS/cm/yr)
- 85% of downward trending sites (29) had small rates of change (< -5 µS/cm/yr)



Results: Seasonal changes for WRTDS trend sites

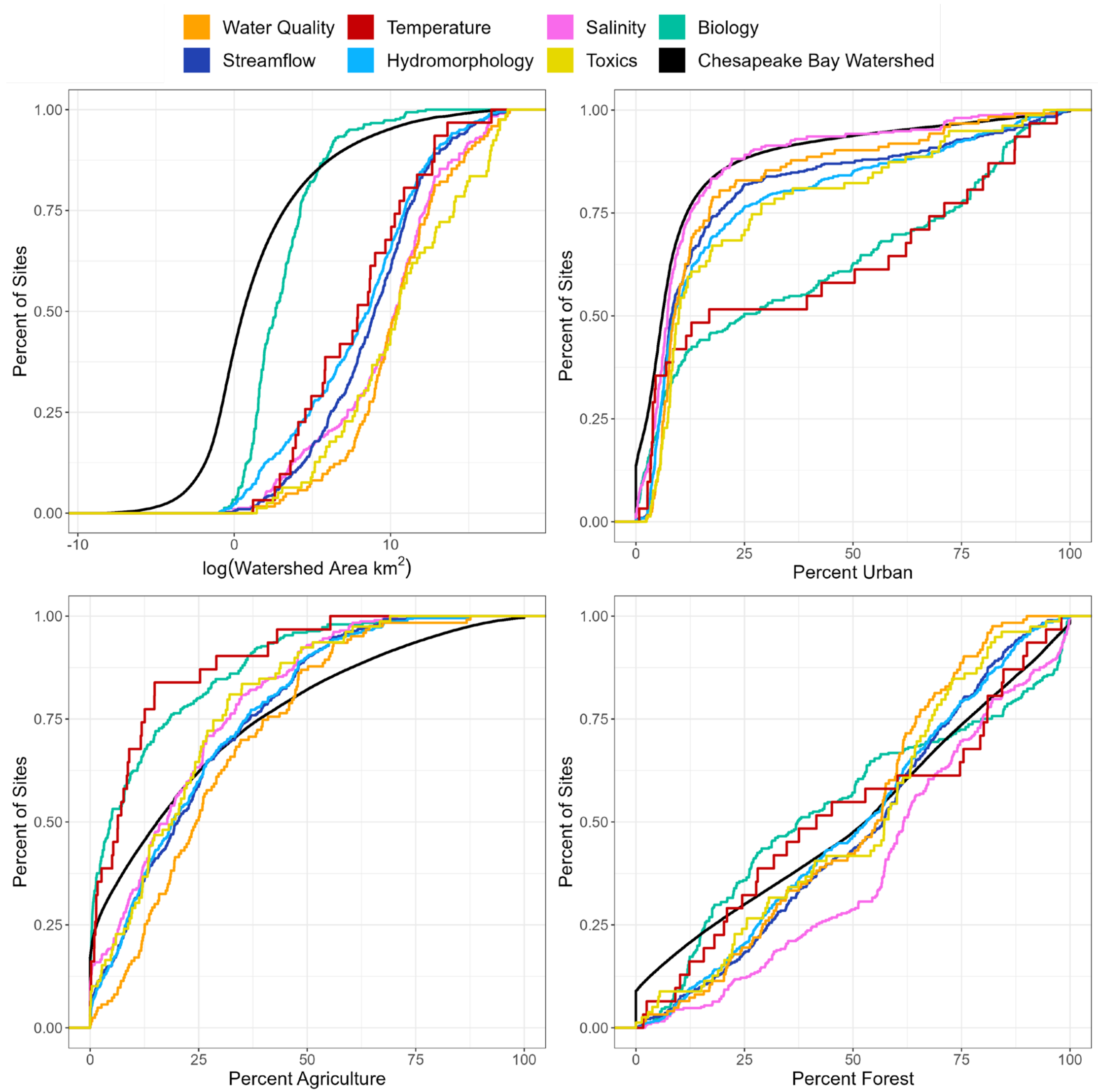


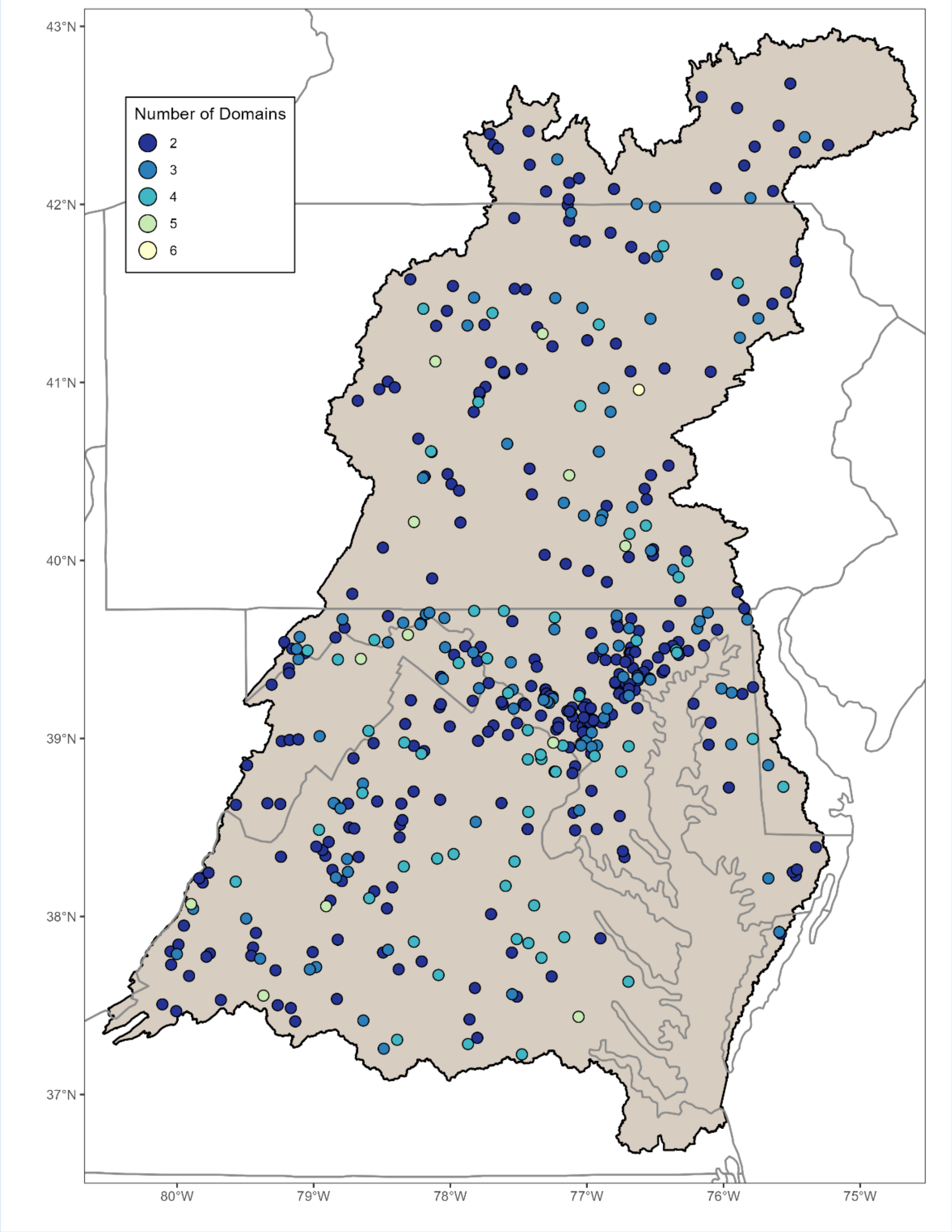
<u>Annualized seasonal change:</u>

- Used predicted daily SC values from WRTDS
- Computed seasonal mean SC for each year
- Computed change in seasonal means between start and end year
- Divided it by the seasonal mean in initial year
- Units are % per year

Rumsey, C. A., Hammond, J. C., Murphy, J., Shoda, M., & Soroka, A., 2023. Science of The Total Environment, 858, 159691. https://doi.org/10.1016/j.scitotenv.2022.159691

Indicator site representation





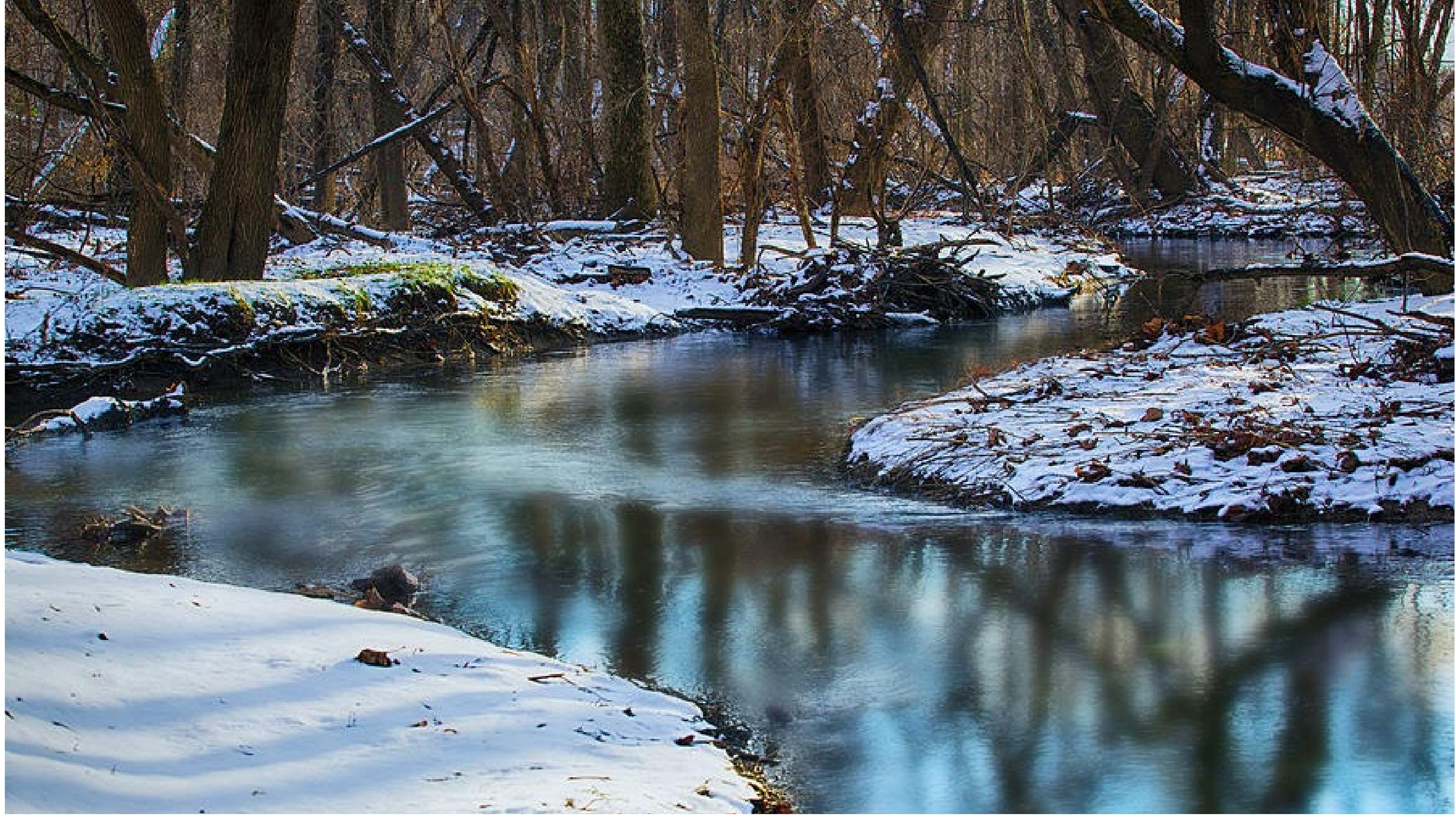
This information is preliminary and is subject to revision. Not for Citation or Distribution.

Takeaways and next steps

- Only 15% of sites (43) had 3-year median SC values at or below background SC
- SC is increasing at the majority of WRTDS trend sites (60%)
- Rates of increase were modest (< 5 µS/cm/yr), except in urban regions where SC is increasing at a faster rate
- Rate of change are greatest in winter and spring months at sites with increasing SC trends

<u>Next steps (FY24 and beyond)</u>

Publish SIR (FY24)
Trend explanation based on stakeholder needs
Incorporate major ion information (Cl-, SO_4^{2-})
Re-run trends analysis using refreshed data



Project 2: Predict SC and departures from background SC across all freshwater tributaries

Rosemary Fanelli, SAWSC, U.S. Geological Survey
Joel Moore, Towson University
Charlie Stillwell, SAWSC, U.S. Geological Survey
Andrew Sekellick, MD-DE-SC WSC, U.S. Geological Survey
Rich Walker, Upper Iowa University

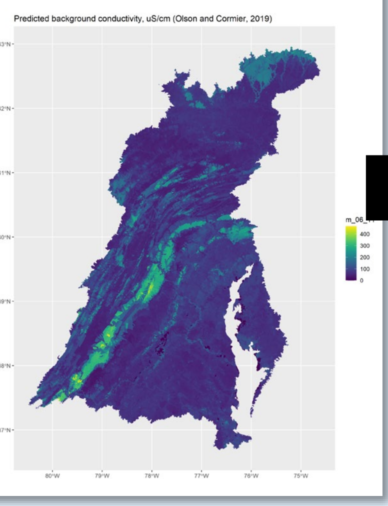
Conductivity assessment – Why is this important

- More information on **where streams are most impacted by freshwater salinization** is needed
- Companion assessment to three other regional assessments to predict basin-wide conditions:
    - Benthic macroinvertebrates (Maloney et al. 2022; https://doi.org/10.1016/j.jenvman.2022.116068)
    - Fish populations (Maloney et al., 2021; https://doi.org/10.1016/j.ecolind.2021.108488)
    - Physical stream habitat metrics (Cashman et al., *in prep*)
- All assessments use NHDplus v2.1 (1:100K scale) network as geospatial framework
- Assessments will be used in a synthesis in FY25

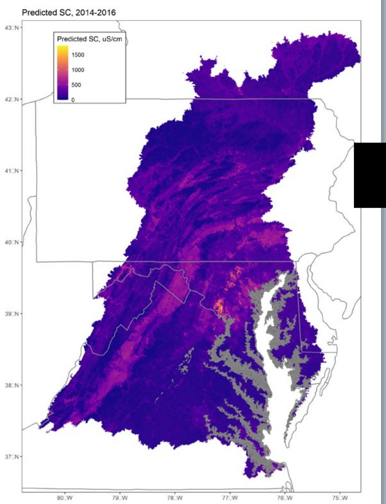
Data and methods

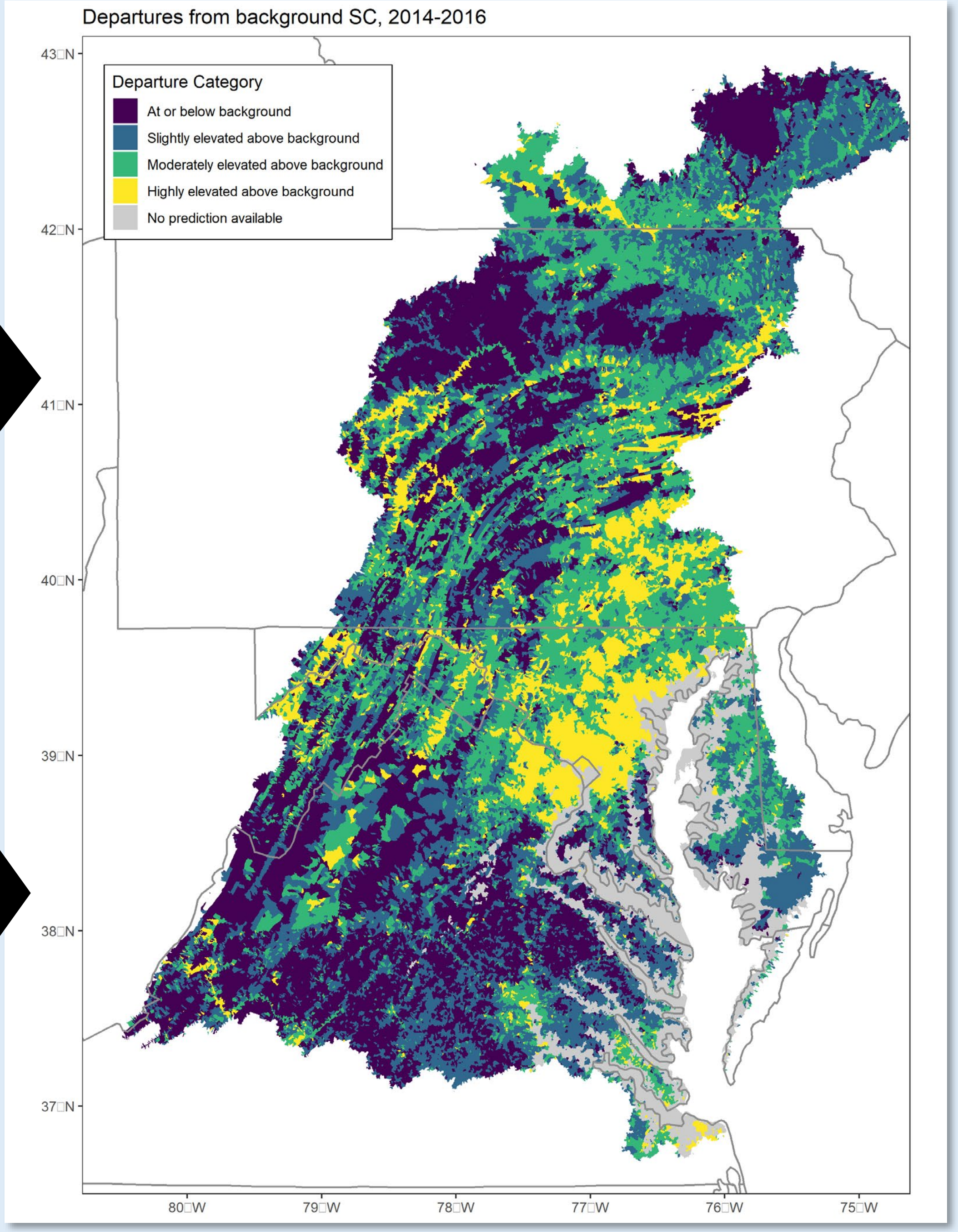
- **Input datasets**
  - Observed SC (*Fanelli and others, 2023*)
  - Watershed characteristics: land use, climate, geology, point sources
  - Modeled background SC *(Olson and Cormier 2019)*
- **Predicting SC**
  - Used 1:100K NHD v 2.1
  - Grouped observations into four time periods (2001, 2006, 2011, 2016)
  - Used random forests regression models to predict median annual SC for four time periods
- **Quantifying departures**
  - Accounted for background SC to determine departures from background SC

Background SC



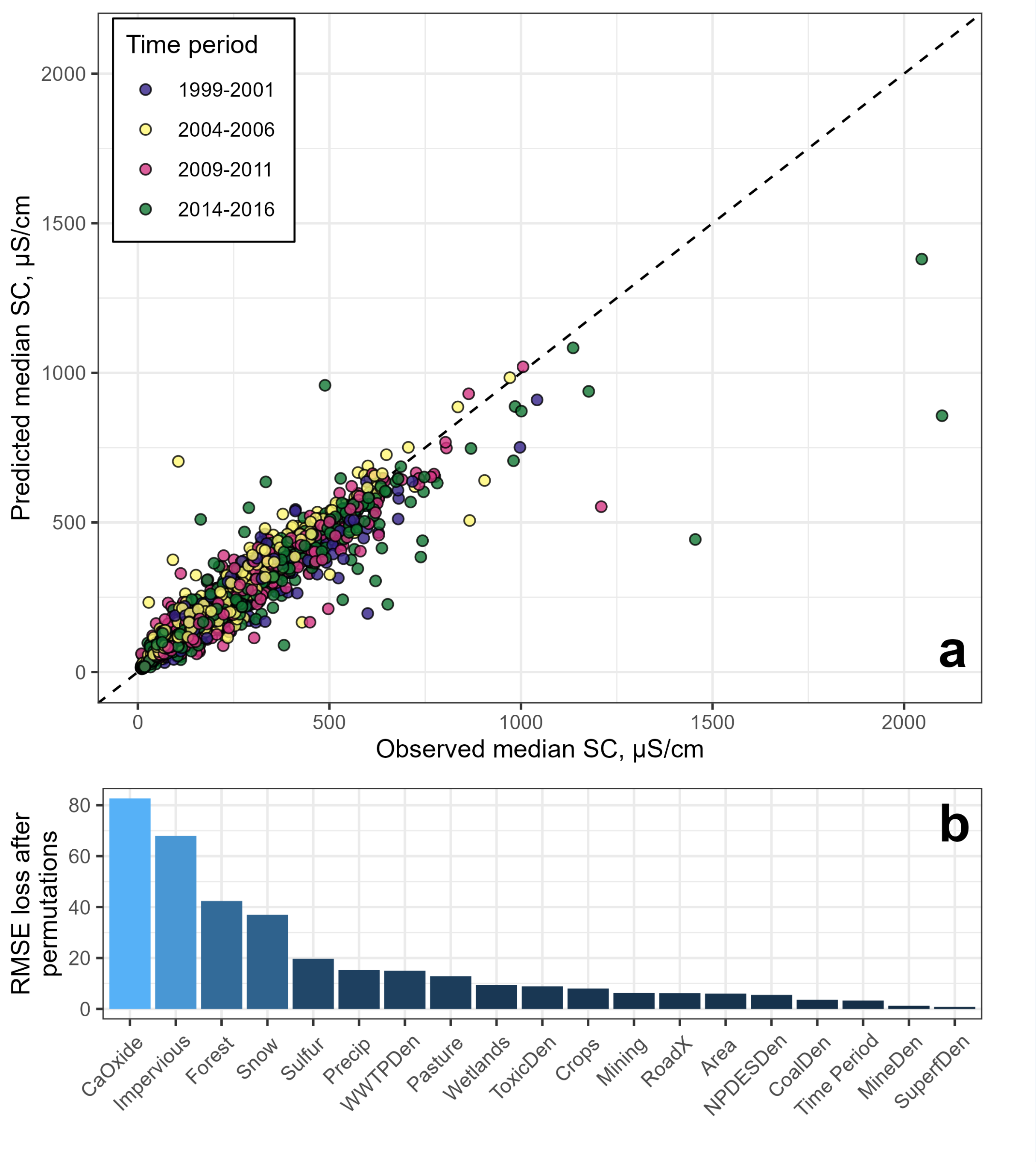
Predicted SC



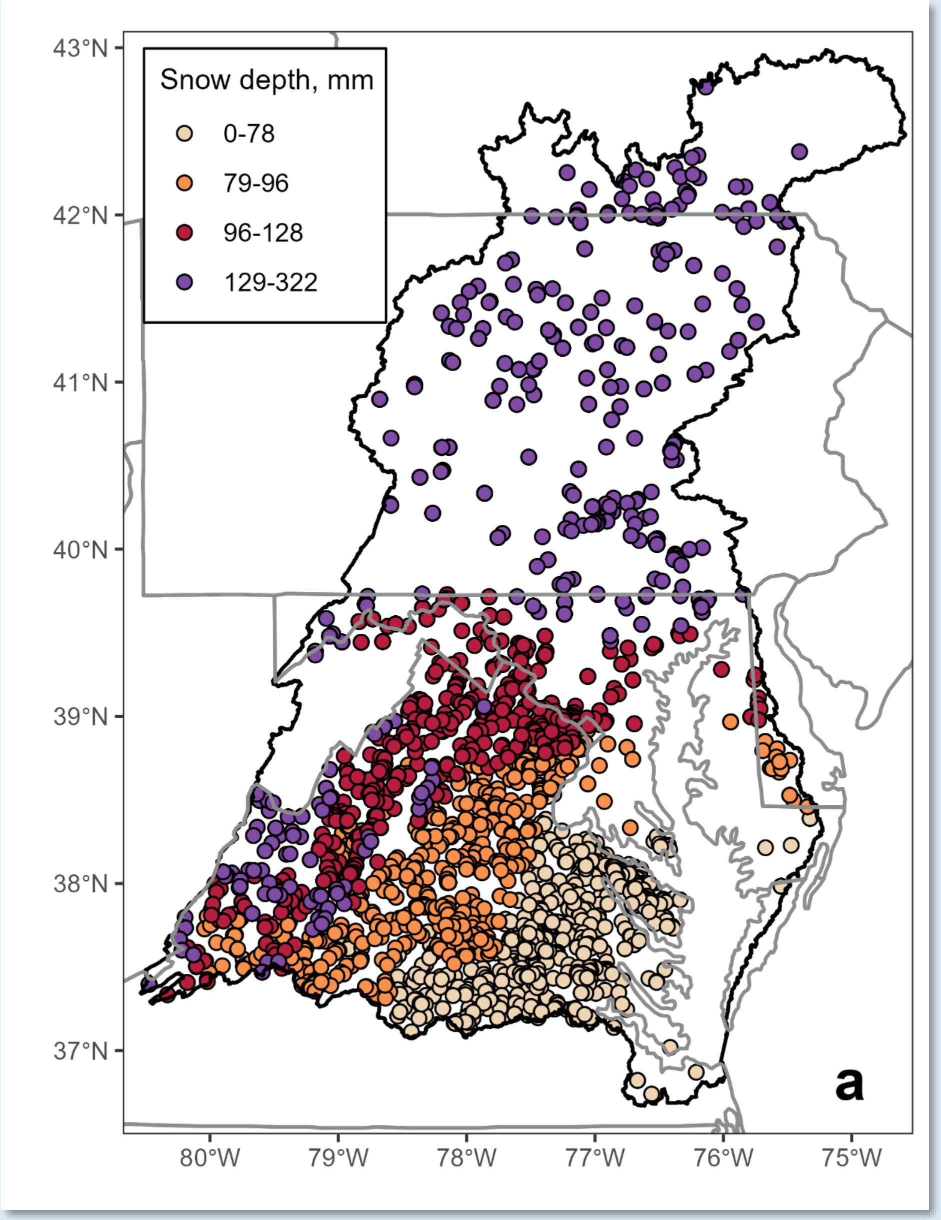


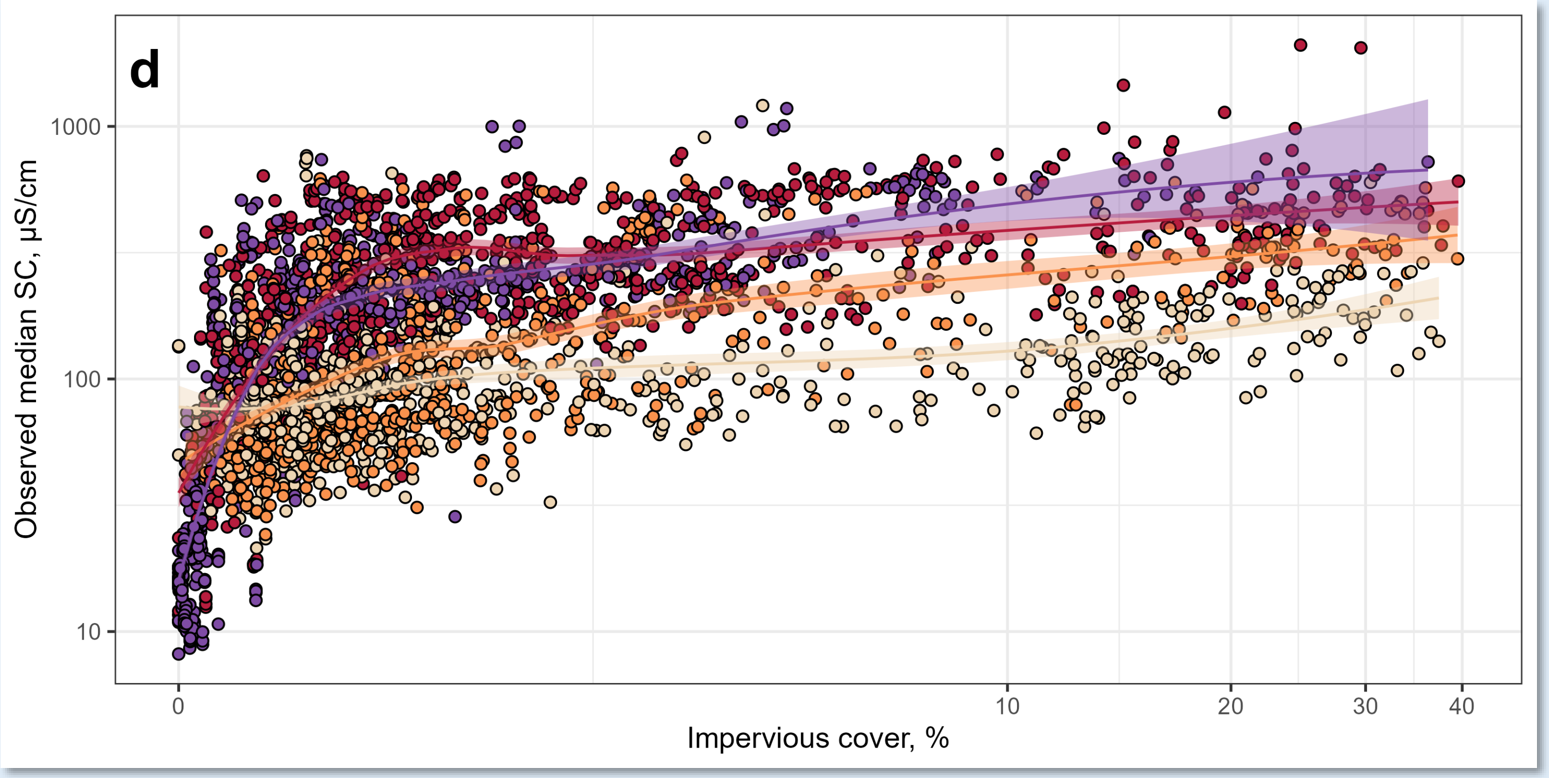
Model set up and performance

- **Random forest regression modeling**
  - Response variable = Median annual SC
  - 18 predictor variables including time period
  - Stratified sites in testing and training datasets based on carbonate geology
  - Model parameters were tuned in 10-fold cross validation procedure
- **Results**
  - MAE = 38.4 µS/cm
  - Mean R^2 = 0.81
  - Top three variables: calcium oxide (proxy for carbonate geology), impervious cover, and forest cover



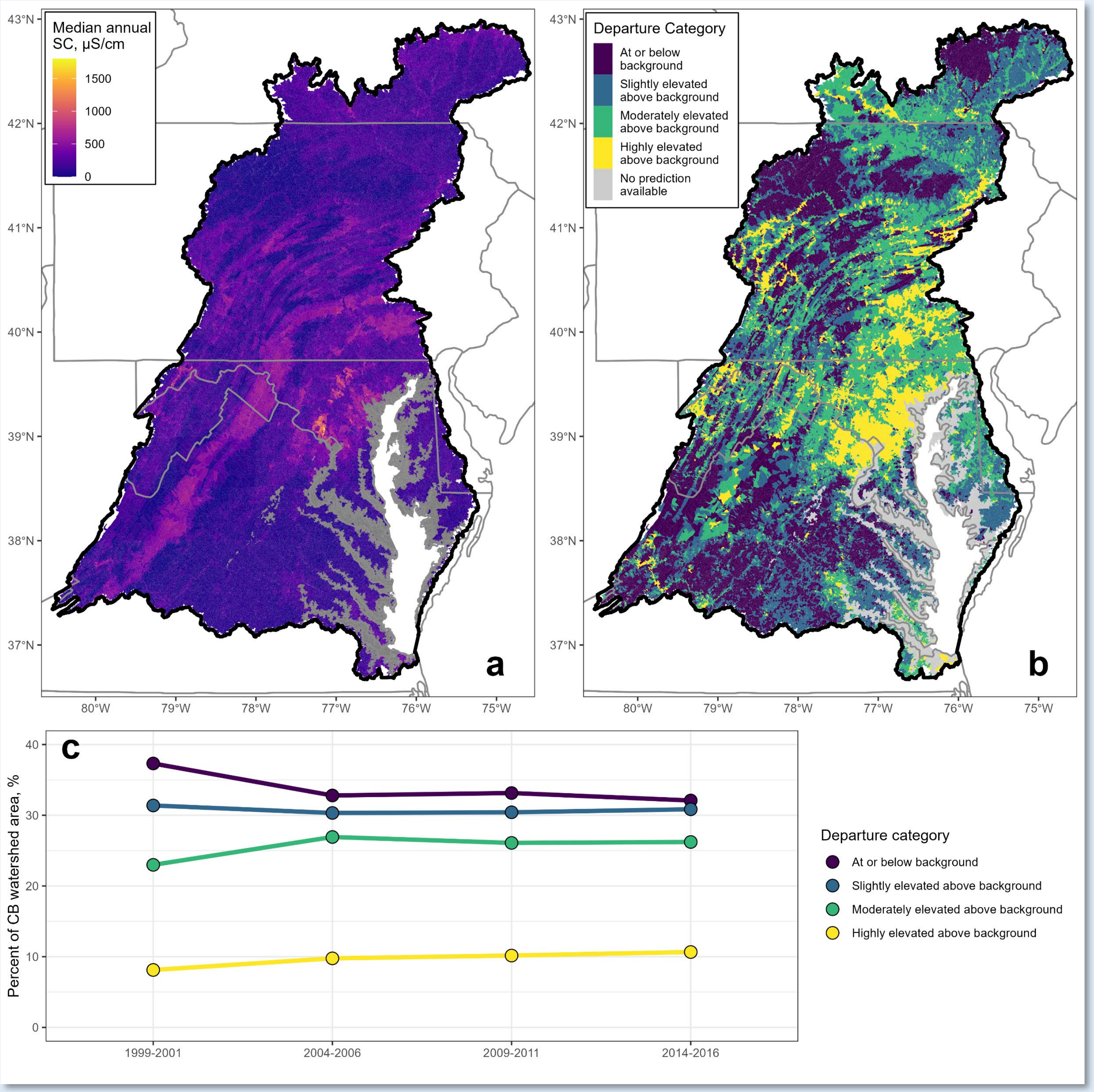
Results: Snow depth **amplifies** the effect of impervious cover on SC





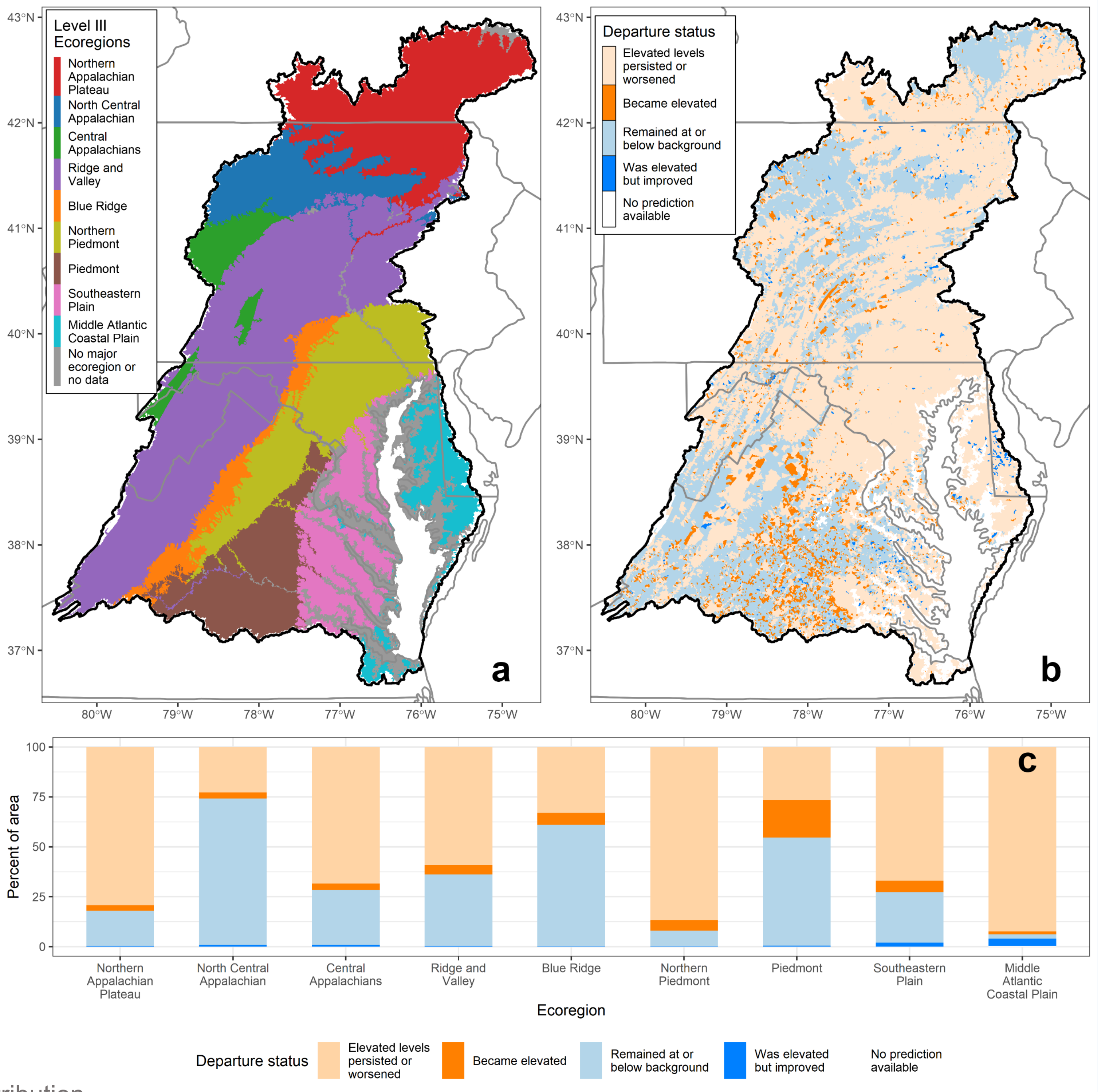
Basin-wide predictions of SC and SC departures

- Predicted median annual SC varied from 10-1,720 µS/cm
- Only 37% of CB watershed had SC values at or below background SC in 2001, declined to 32% in 2016
- Percent of watershed with highly elevated SC increased from 8.1% to 10.7% from 2001-2016



Changes in departure status across ecoregions

- Change in departure status = Change in predicted SC from 2001-2016
- SC in North Central Appalachians and Blue Ridge largely remained at or below background SC
- Previously elevated SC levels persisted in Northern Piedmont and Coastal Plain ecoregions
- Piedmont had largest total area that became elevated during study period



Takeaways and next steps

- Carbonate geology important predictor of SC
- SC increases with greater impervious cover, and snow depth amplifies the effect
- Almost two-thirds of the CB watershed has SC values above background SC; pattern persists over time
- Other land uses (logging, agriculture) may contribute to elevated SC in certain ecoregions

Next steps (FY24 and beyond)

Publish journal article and data release
Re-run analysis at 1:24K scale (FY25)
Incorporate data into regional synthesis (FY25-26)

Questions or feedback?

Contact info:

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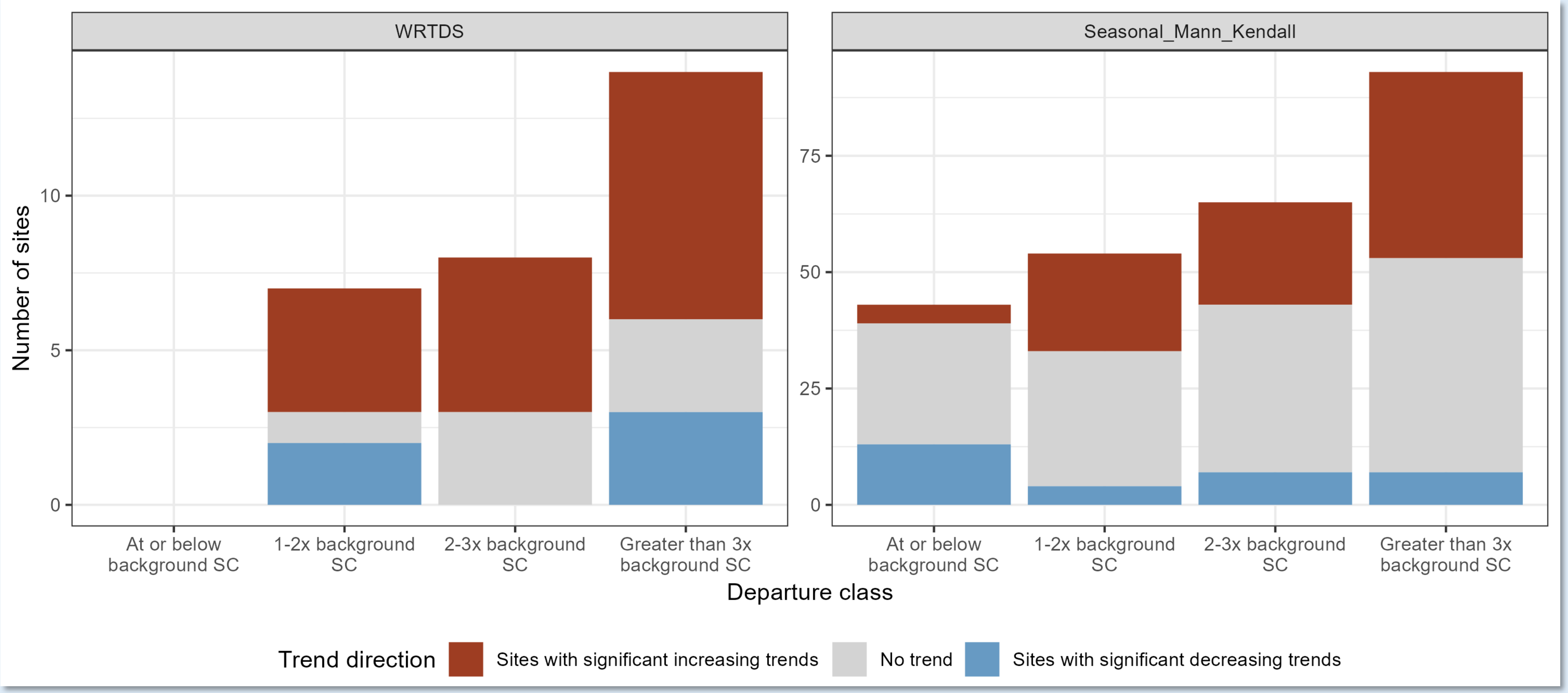
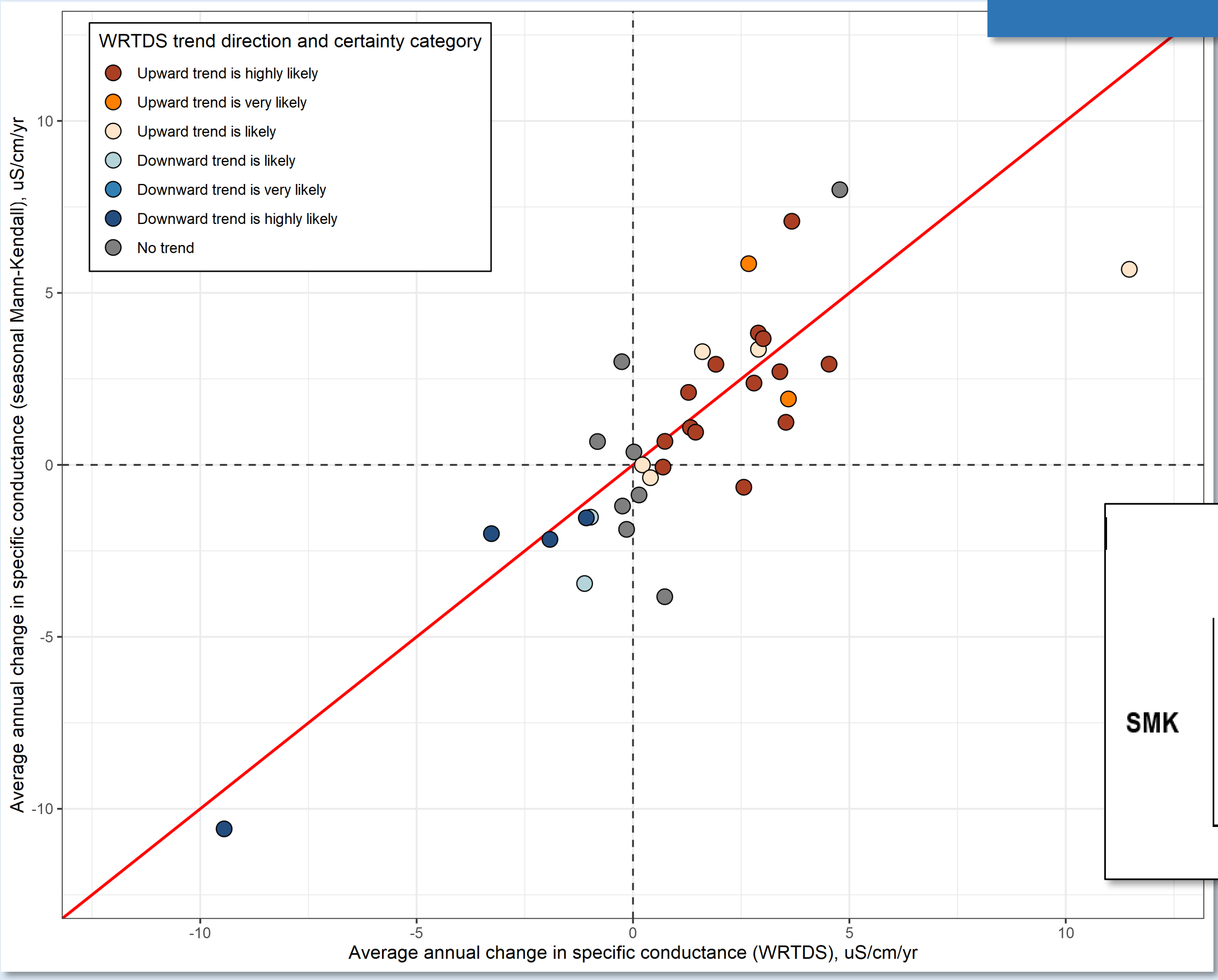
SC status and trends



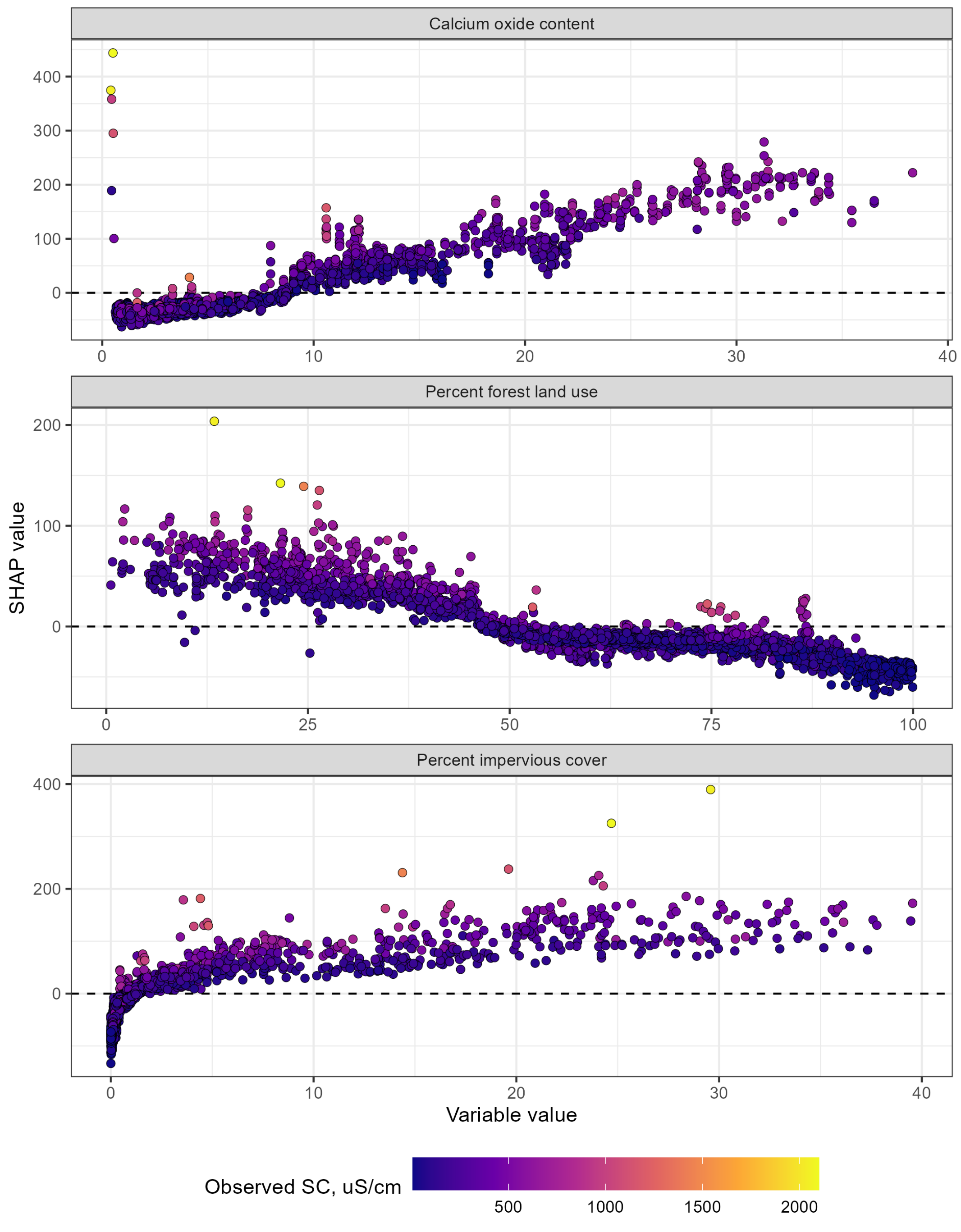
Results: SC trend comparison



		WRTDS		
		Not significant	Significantly decreasing	Significantly increasing
SMK	Not significant	9-percent	6-percent	29-percent
	Significantly decreasing	9-percent	11-percent	0-percent
	Significantly increasing	6-percent	0-percent	31-percent

Shapley values for top three predictors

- Shapley (SHAP) values = feature contributions
  - Describe the additive contributions of a single variable to a predicted SC value
- Calcium oxide SHAP values were positive when Calcium oxide >8%
- Forest cover SHAP values were negative when forest cover > 50%
- Impervious cover SHAP values were positive when impervious cover >1%



Reach-scale changes in departure status