USGS/SHWG Stressor summary project :

Identifying key stressors driving biological impairment in freshwater streams in the Chesapeake Bay watershed

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U.S. Geological Survey
Toxic Contaminant Workgroup Meeting
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USGS-SHWG collaboration research questions

1. Which stressors and drivers most affect stream health?
   - Stressors = water quality, toxic contaminants, habitat suitability, altered flow, temperature, etc.
   - Drivers = Climate change, land use change, point sources, energy extraction activities
2. Which of these stressors can be changed through management activities, especially those that align with practices associated with existing TMDLs or new Watershed Implementation Plans (WIPs)?

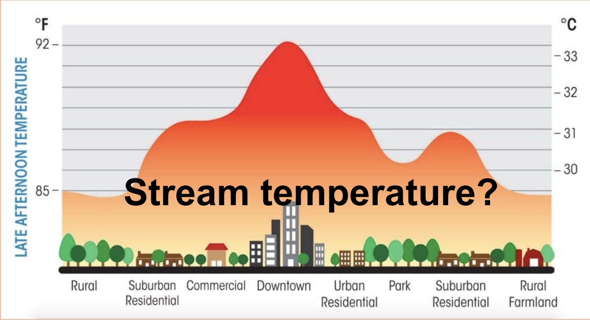
3. How is stream health changing following management implementation, and how can we better characterize the biological and stressor response to management implementation?

Current project addresses Question 1 of USGS-SHWG collaboration

An example: Urban areas

- Degraded ecological condition
- Wide range of potential stressors

Urban Land-Use



Stream ecological Condition

- Which stressor(s) are most important?
- What pathways should management actions target?

Project goal and scope

Question: Which stressors are most affecting stream health in freshwater ecosystems in the Chesapeake Bay watershed?

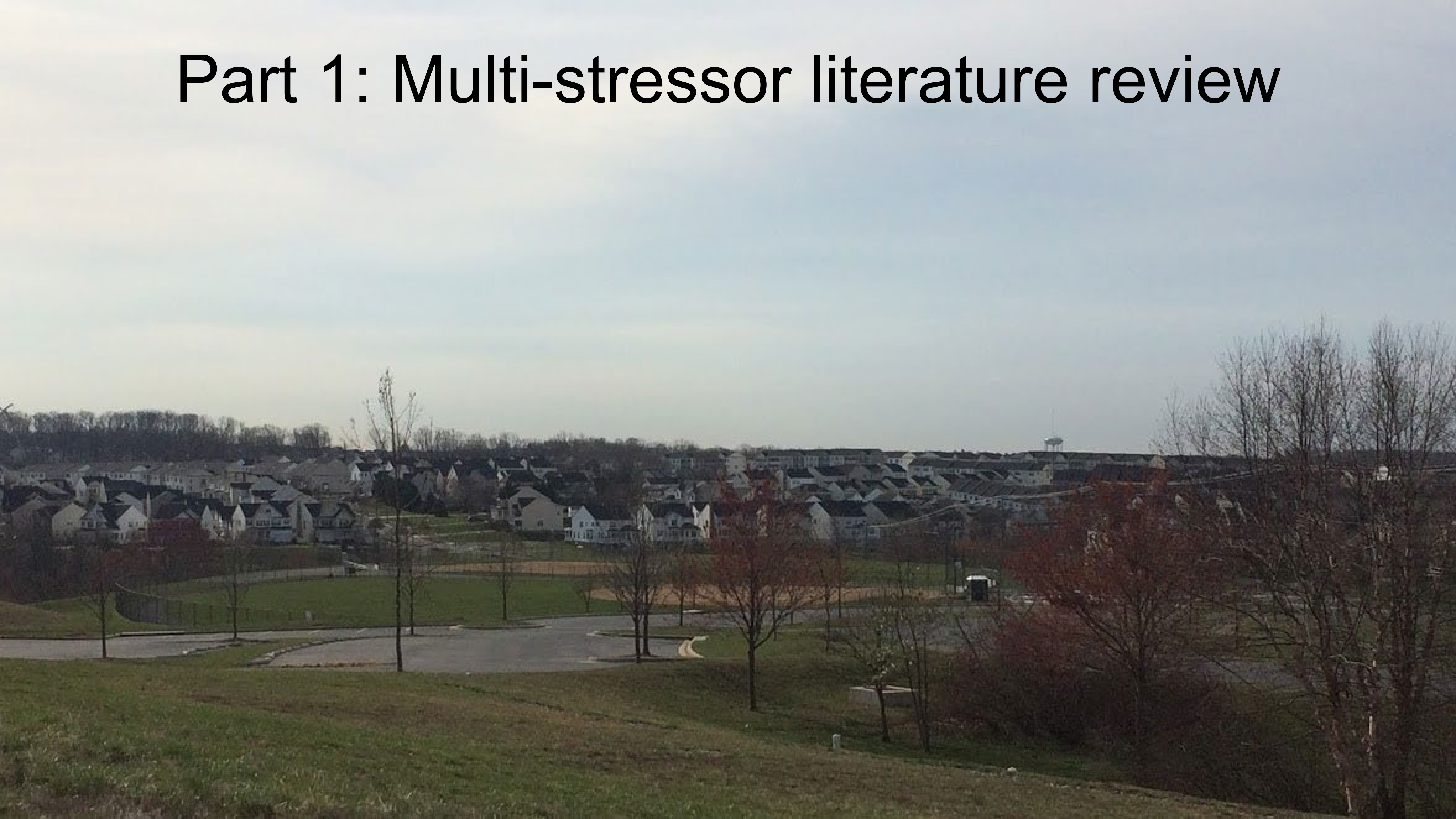
Stream health = measures of benthic community composition, function, or other response

Stressor = A local factor that negatively affects patterns in stream health

Drivers = Factors that cause changes in stressor conditions or levels

- Use existing information to summarize current understanding of the dominant stressors in different landscape settings/originating from different drivers
- Summarize two types of stressor sources:
  - Scientific literature
  - Jurisdictional/state impairment lists

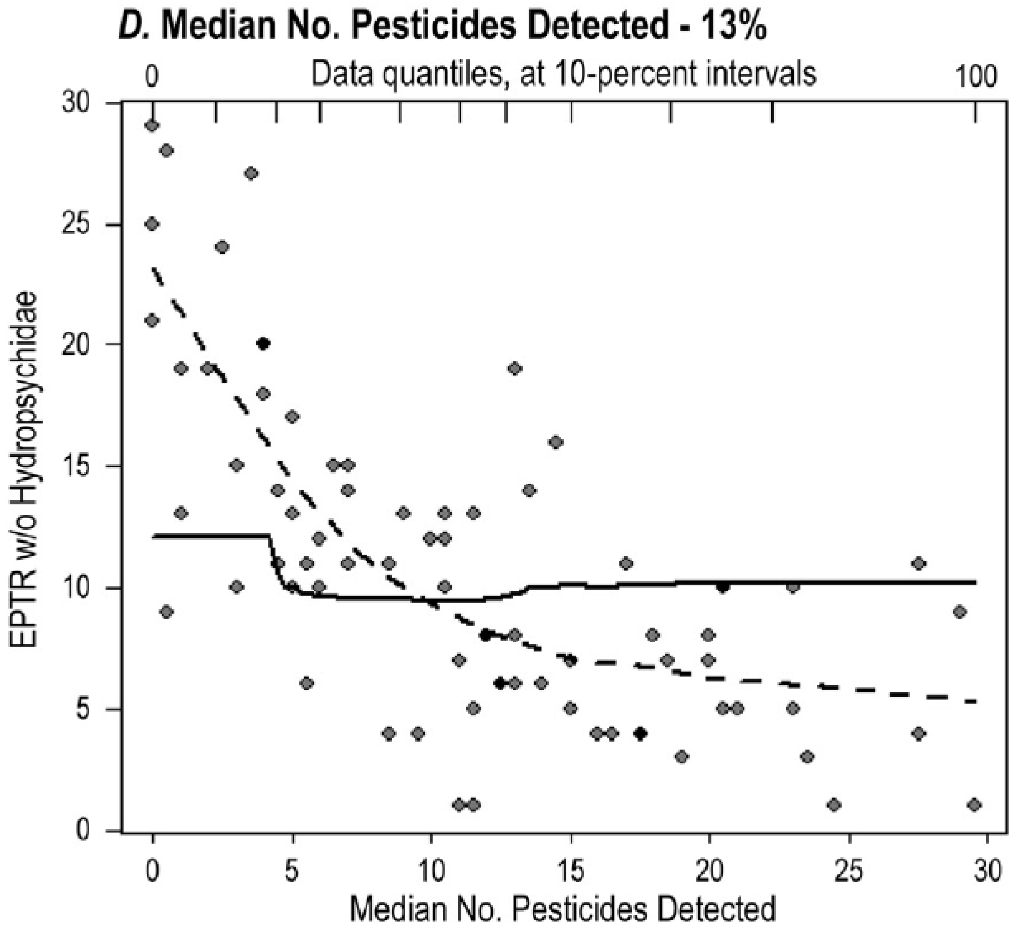
Part 1: Multi-stressor literature review



Literature review and analysis

- **General literature search using key words**
- **General study characteristics**
  - Drivers examined in the study
  - Stressors measured in the study
  - Study design (setting, number of obs. units, etc.)
- **Methodology**
  - How stream health was measured (IBI, drift rates)
  - How stressor(s) were quantified
  - Stat methods to examine stressor-bio relationships
- **Key conclusions**
  - Information on stressor importance (reported as binary)
- **Conducted frequency analysis on subset of studies**
  - Eligibility based on statistical analysis
  - 34 studies included

Extracting key information from literature



Effects of urban multi-stressors on three stream biotic assemblages

Waite and others 2019 (*Science of the Total Environment* 660: 1472-1485)

- **Study design**: 75 sites along urbanization gradient
- **Other stressors measured**: Nutrients, DO, stream temperature, geomorph (habitat), flow, sediment contaminants
- **Analysis:** Boosted regression trees
- **Response variables:** EPT richness without hydropsyche, Observed vs expected taxa, total richness

Macroinvertebrate	
EPT richness (EPTR-H) without hydropsyche	VI
DO minimum	34
Flow peak intervals	19
Fungicides - P	14
Median no. pesticides detected - W	13
TN median	12
Phenylpyrazole insecticides – W	8

Provisional results, for feedback only

Stressor category definitions

In-stream stressors

- Toxic contaminants: Includes metals, organic compounds, pesticides as separate sub-category
- Geomorphology: Includes physical habitat measures and measures of suspended sediment/turbidity
- DO: Dissolved oxygen
- Acidity: pH and alkalinity effects
- Flow: Measures of flow (e.g., discharge) or flow alteration
- Nutrients: Nitrogen and phosphorus
- Salinity: Salinity, specific conductance, or major ions (Mg, Cl, Na, etc.)
- Temperature: stream temperature

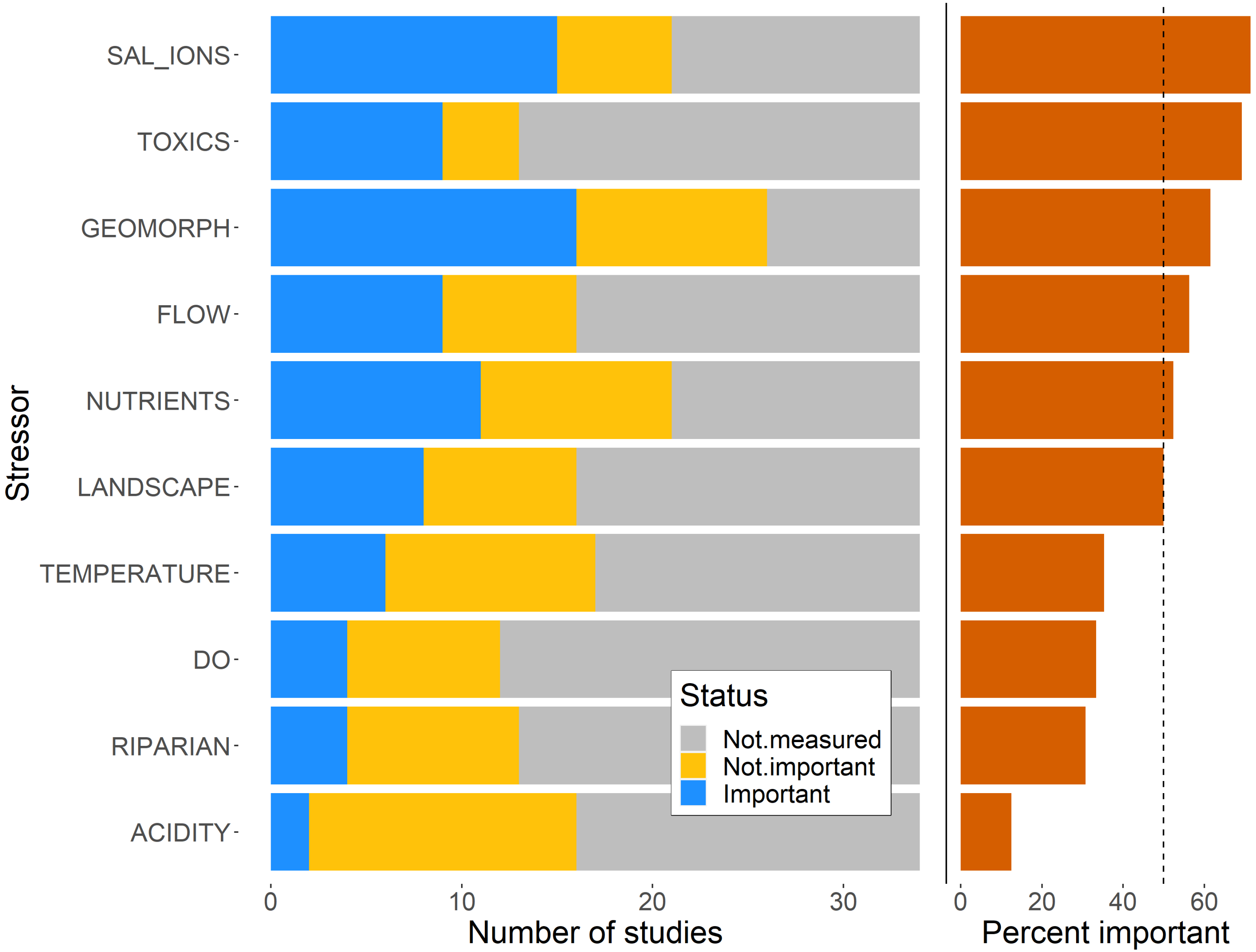
Other factors

- Landscape: Landscape scale factors (percent mined, percent impervious cover)
- Riparian: measures of riparian zone quality/alteration (e.g., percent riparian buffer in ag production)

Major stressors- all studies (n = 34)

Lit review analysis results

- Number of studies that measured the stressor
- Number of studies that reported the stressor as important
- Percent of studies that measured the stressor and reported it as important based on their statistical analysis



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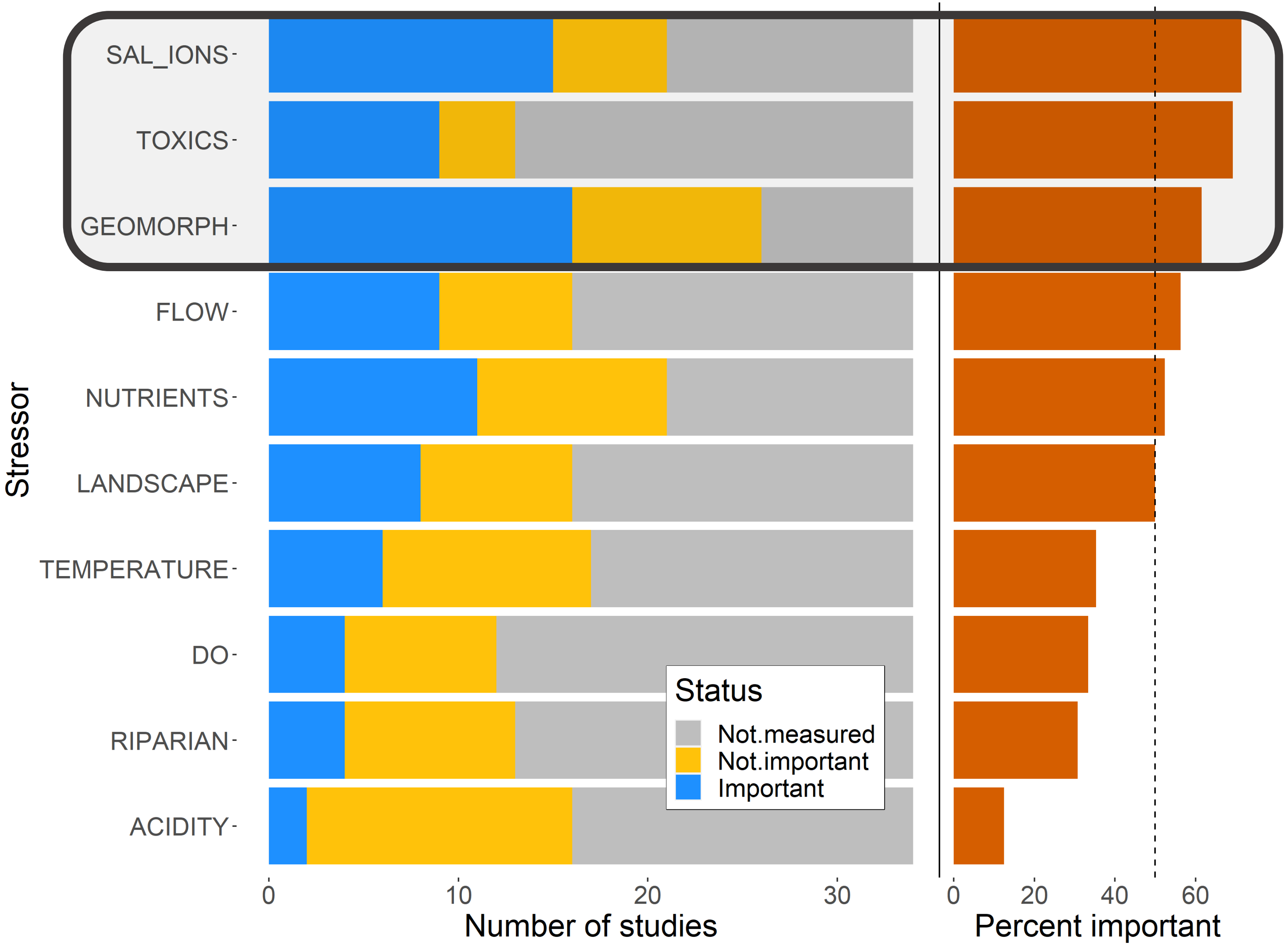

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Major stressors- all studies (n = 34)

<u>Summary of salinity studies</u>

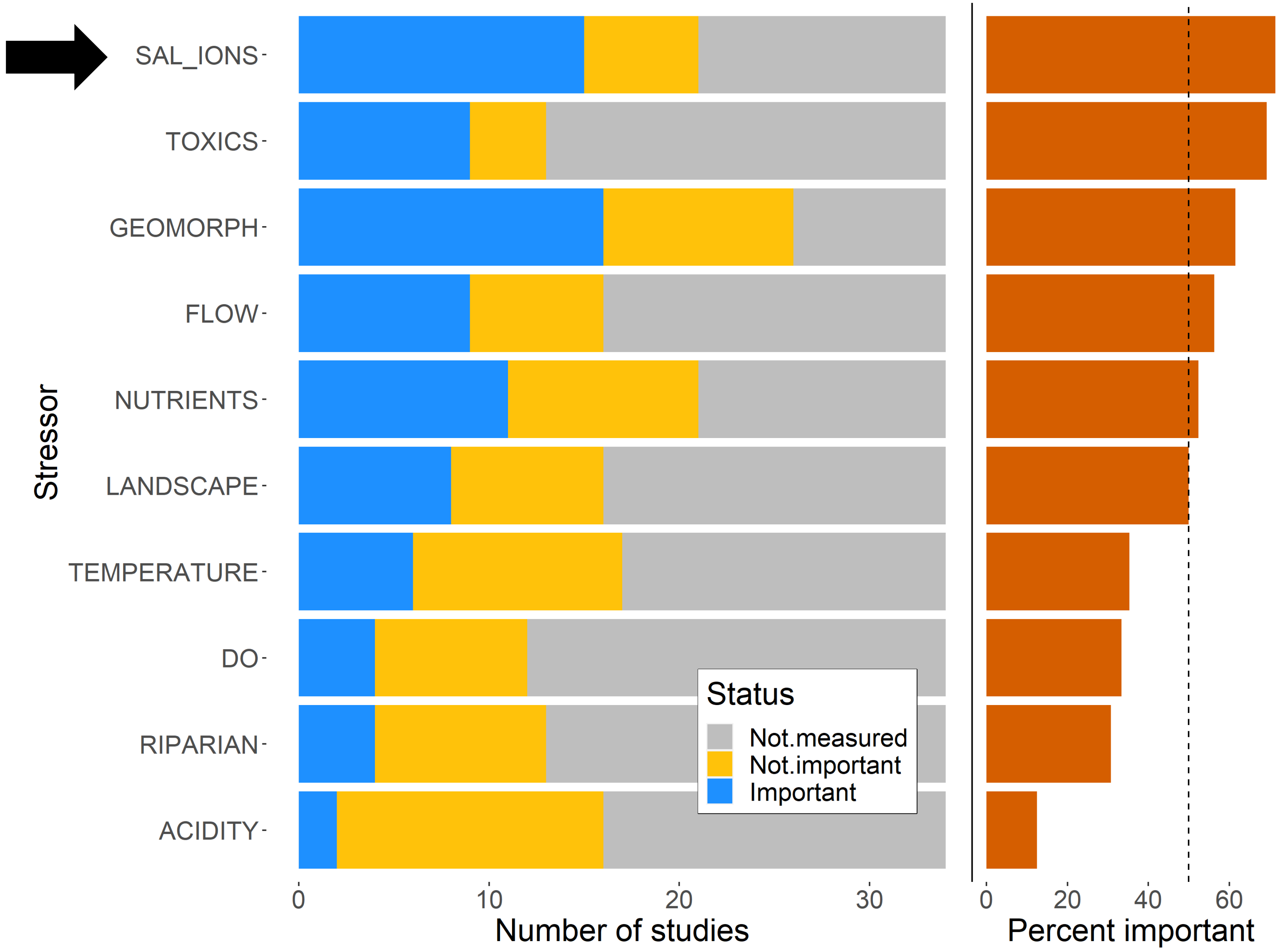
21 studies measured salinity
16 studies (71%) found it important

<u>Measurements</u>

- Conductivity/SC
- SO_4, Ca, Mg, Cl also reported

<u>Common settings/drivers</u>

- Urbanization
- Energy extraction- mining
- Wastewater



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Major stressors- all studies (n = 34)

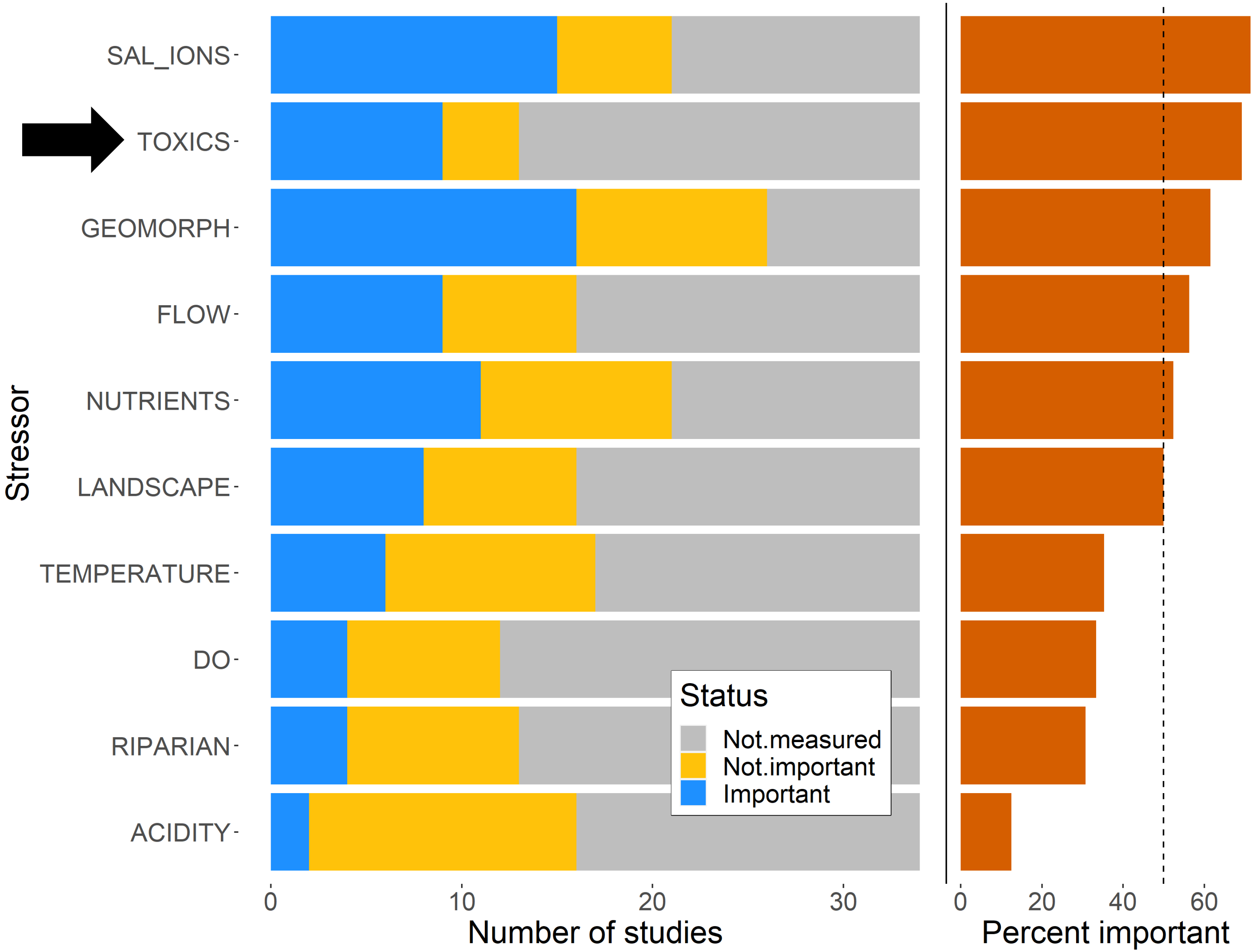
<u>**Summary of toxics studies**</u>
13 studies measured toxics
9 studies (69%) found it important

<u>Measurements</u>

- Metals: Al, Se, Fe, Hg
- Pesticides: Concentrations, number detected, legacy vs contemporary classes detected
- Other organic compounds: PAHs, surfactants

<u>Common settings/drivers</u>

- Urbanization
- Energy extraction- mining
- Wastewater
- Agriculture



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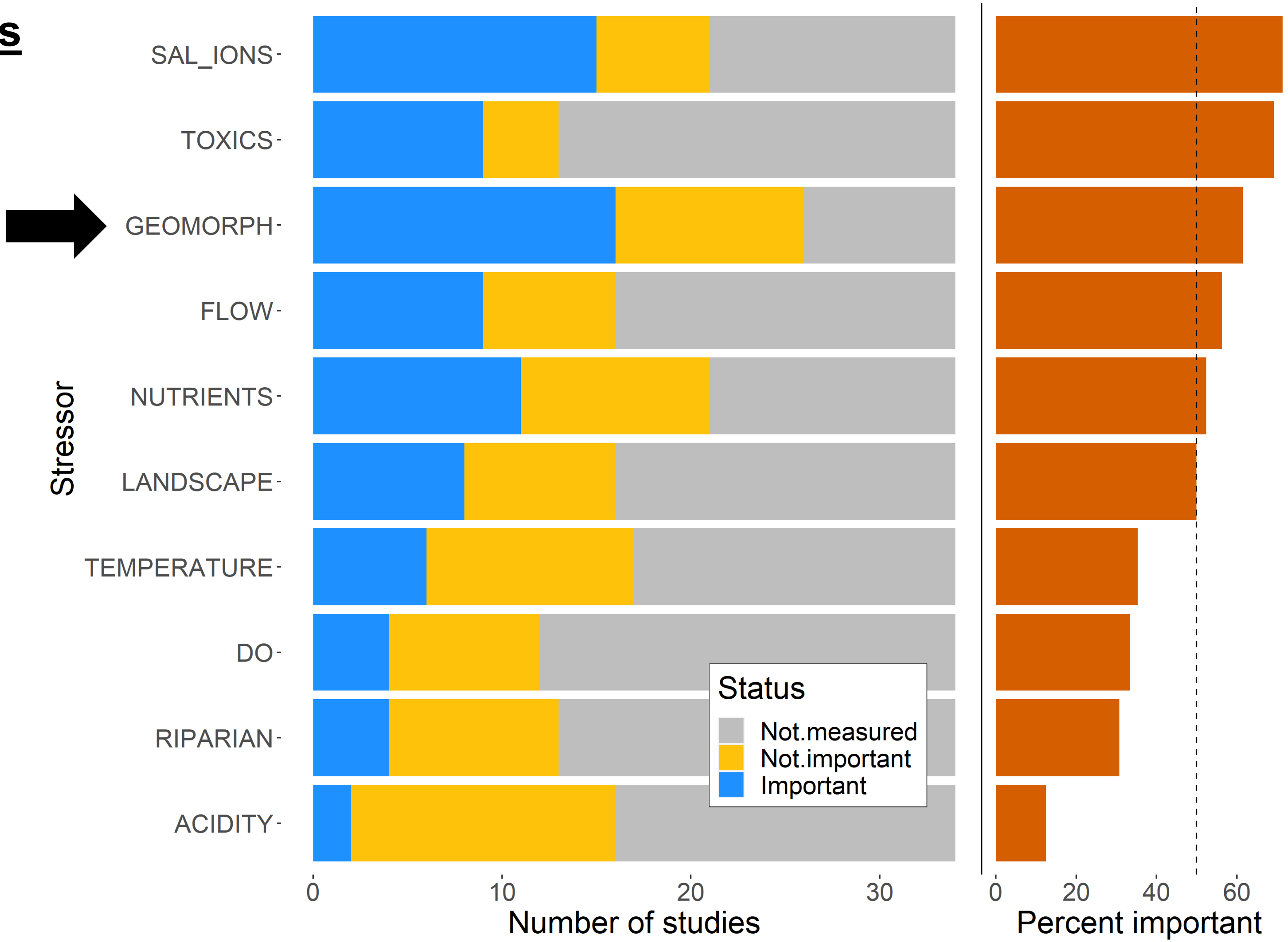
Major stressors- all studies (n = 34)

Summary of geomorphology studies
26 studies measured geomorphology
16 studies (62%) found it important
23 studies (88%) measured habitat

Measurements
- Habitat: Sediment deposition, percent fines, relative bed stability, qualitative habitat scores, water depth or velocity
- Sediment: SSC or TSS concentration

Common settings/drivers
- Mostly agriculture and urban
- Included in some mining studies



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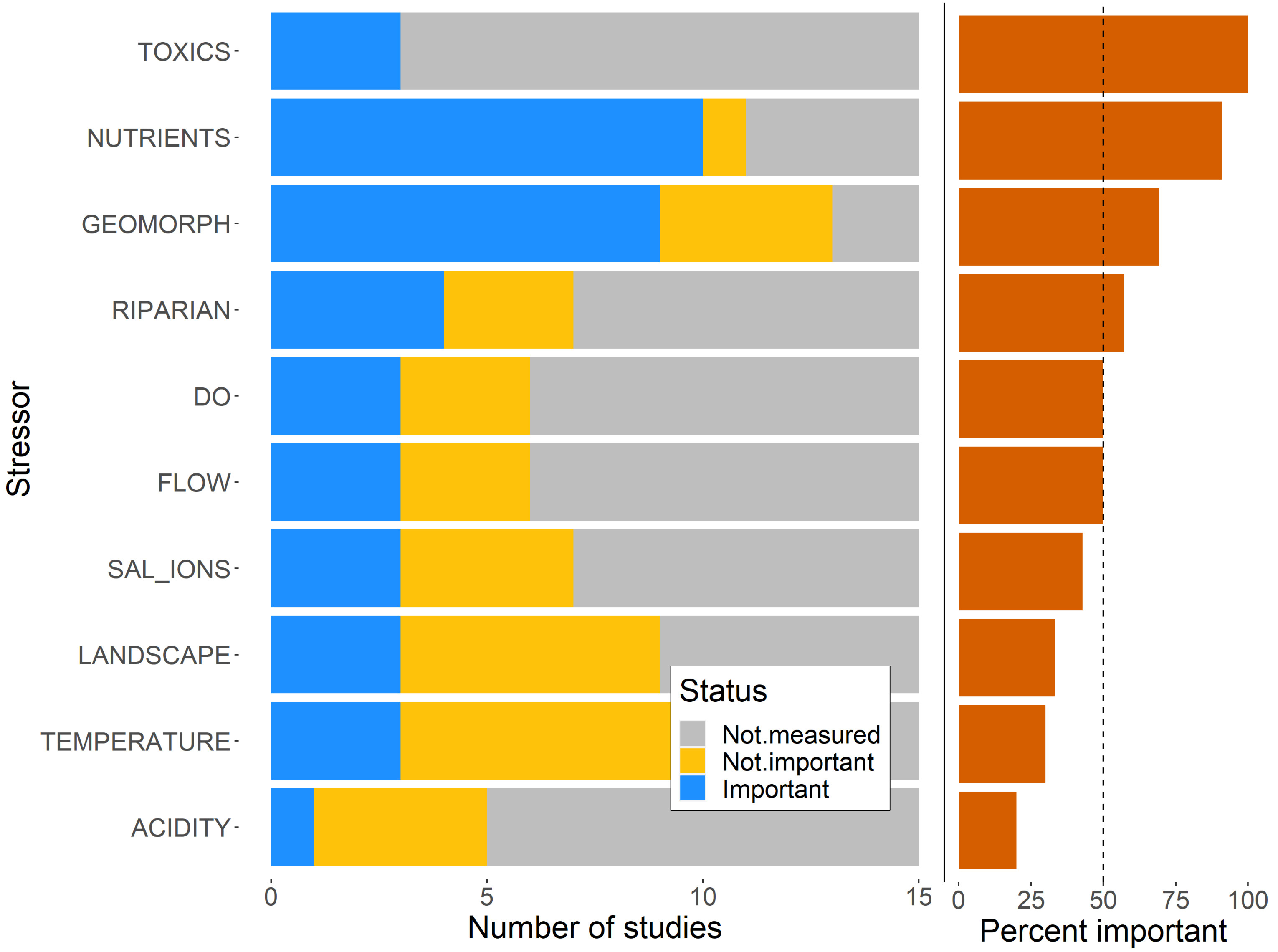
Major stressors- agricultural studies (n = 15)

<u>Top agricultural stressors</u>
1. Toxics
2. Nutrients
3. Geomorphology

- All **toxics** studied were related to pesticide use
- **Nutrients** were always reported as concentrations
- **Geomorph** stressors were almost always expressed as measures of physical habitat



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Major stressors- urban studies (n = 19)

Top urban stressors

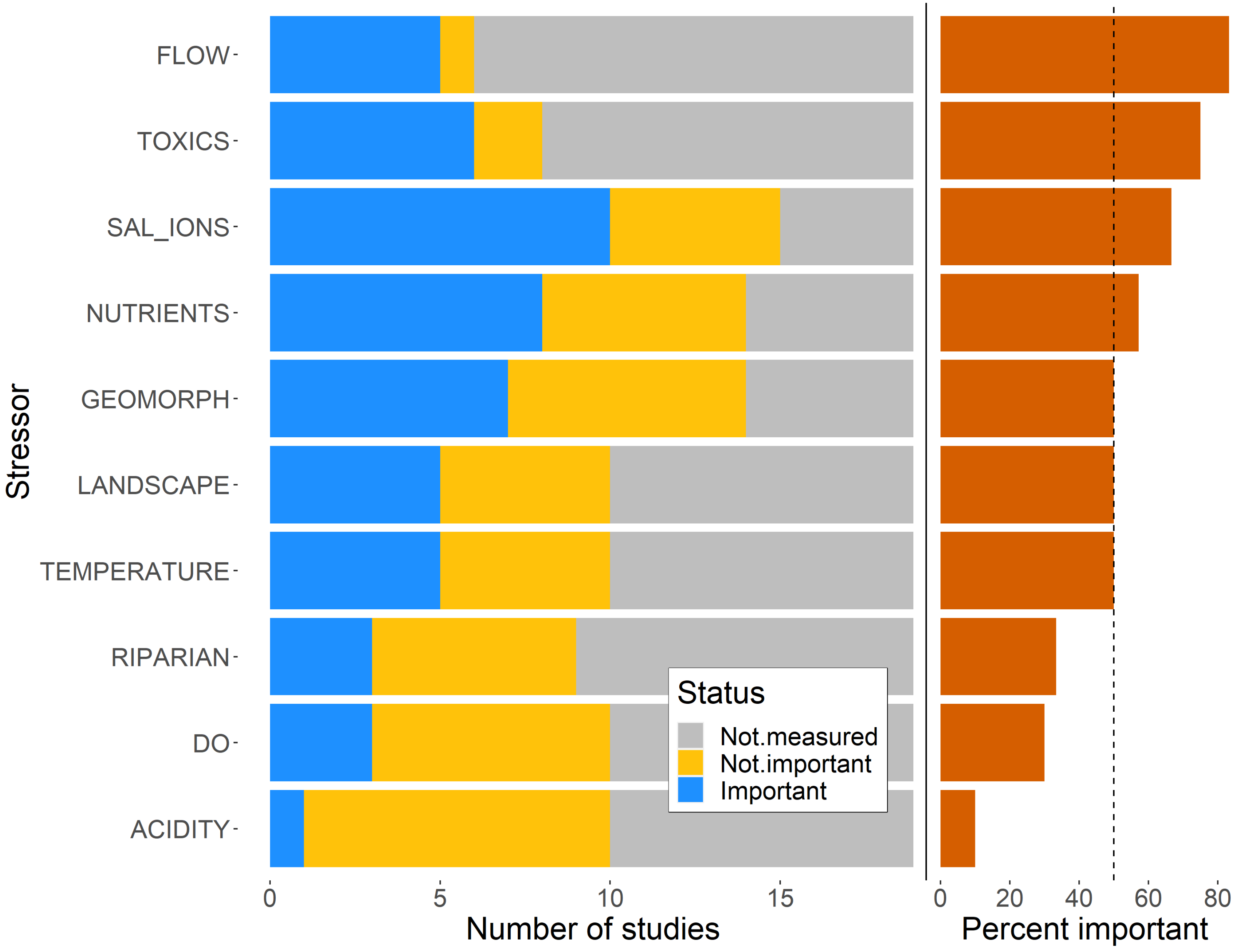
1. Flow
2. Toxics
3. Salinity

Flow as a key stressor

- Only 6 studies measured flow
- Five (83%) reported flow important
- Three studies used high-frequency stage to describe hydrologic alteration

Toxics as a key stressor

- Pesticides
- Other organic compounds (PAHs)
- Metals



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Part 2: State impairment analysis

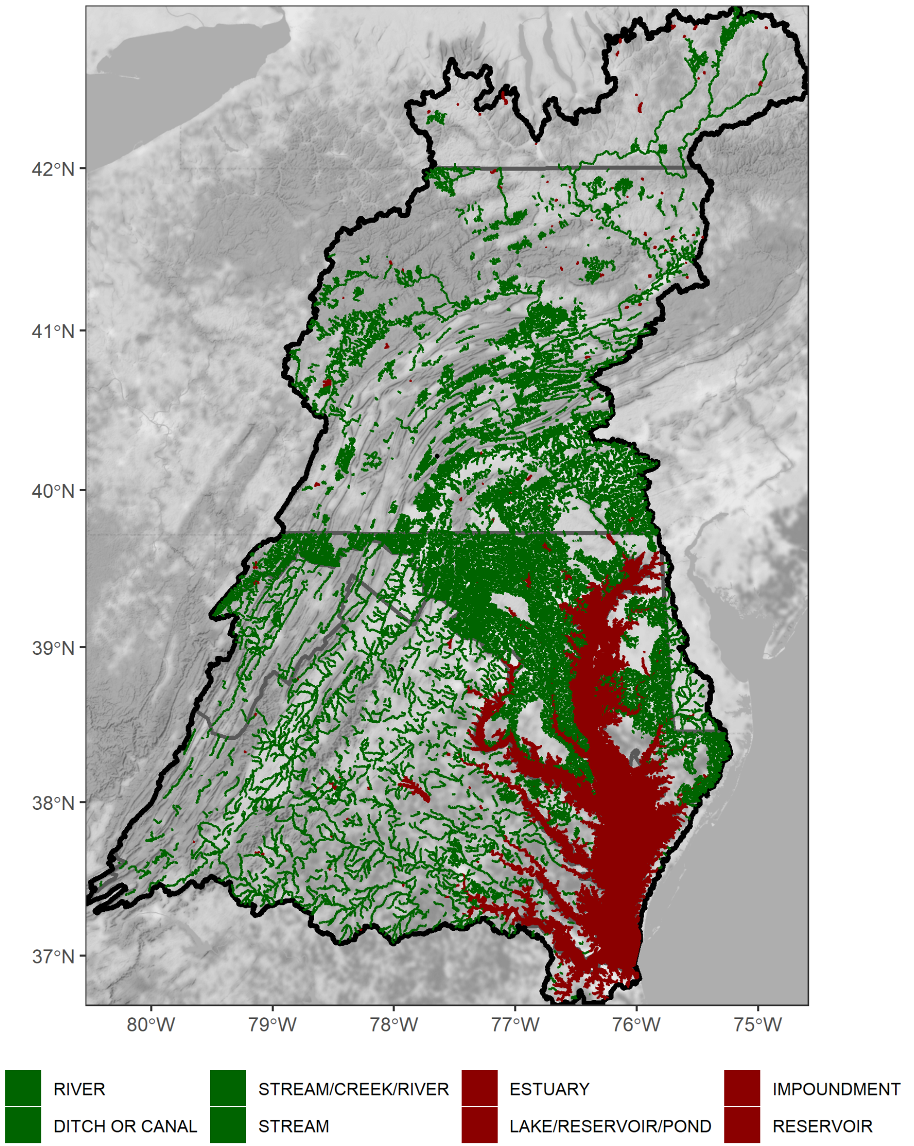
State Impairment Analysis – EPA ATTAINS Database

- Accessed EPA ATTAINS database and GIS
  - ATTAINS - Assessment, TMDL Tracking and Implementation System database
    - 2016 West Virginia
    - 2018 all others

- Harmonize categories and terminology among states
  - Parameter Groups (Stressors)
  - Source Groups (Drivers)
  - Usage Groups

- Only impairments for waterbody types:
  - **IN:** River, Stream, Stream/Creek/River, Ditch or Canal
  - **Out:** ~~Estuary, Lake/Reservoir/Pond, Impoundment, Beach, Reservoir~~

All Chesapeake Bay and Watershed Impairments by Waterbody Type



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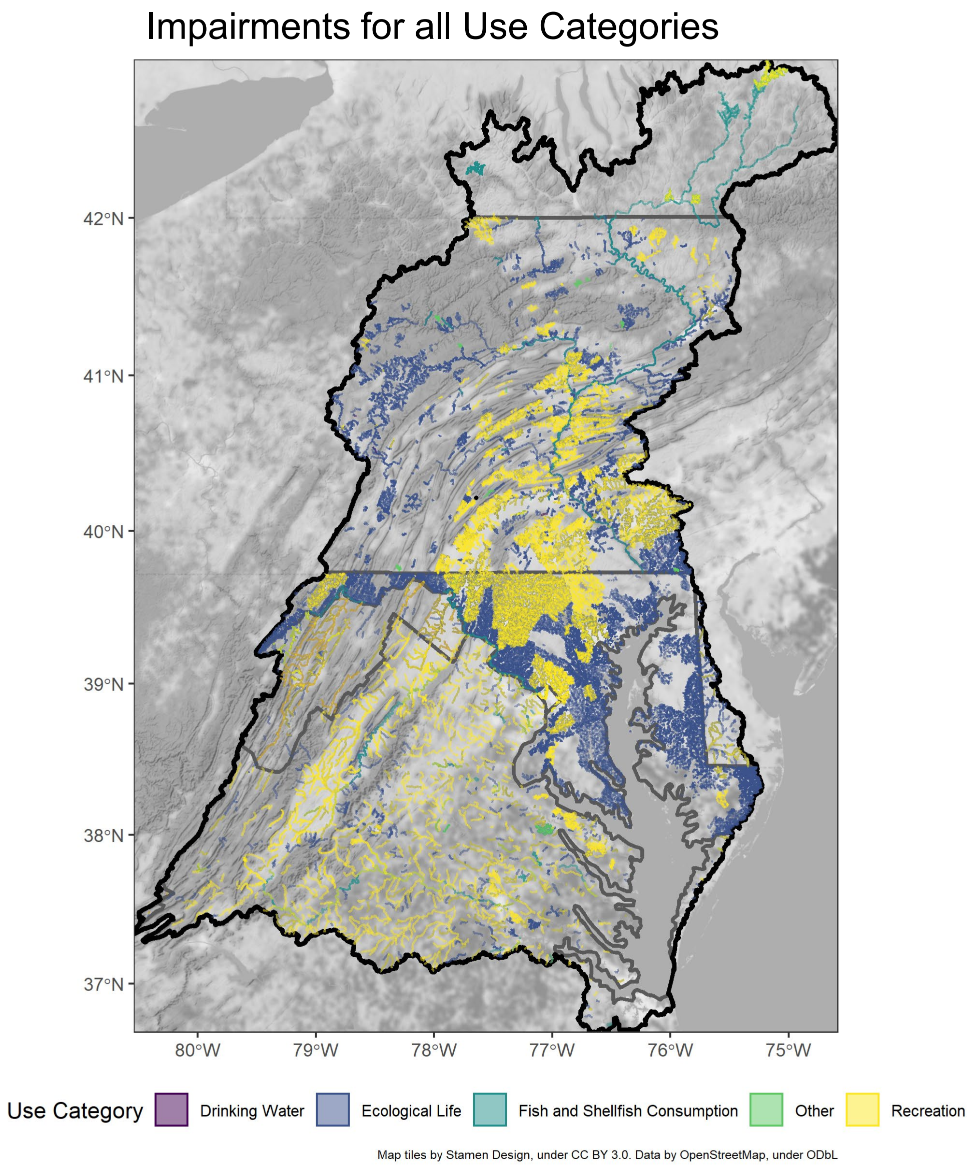
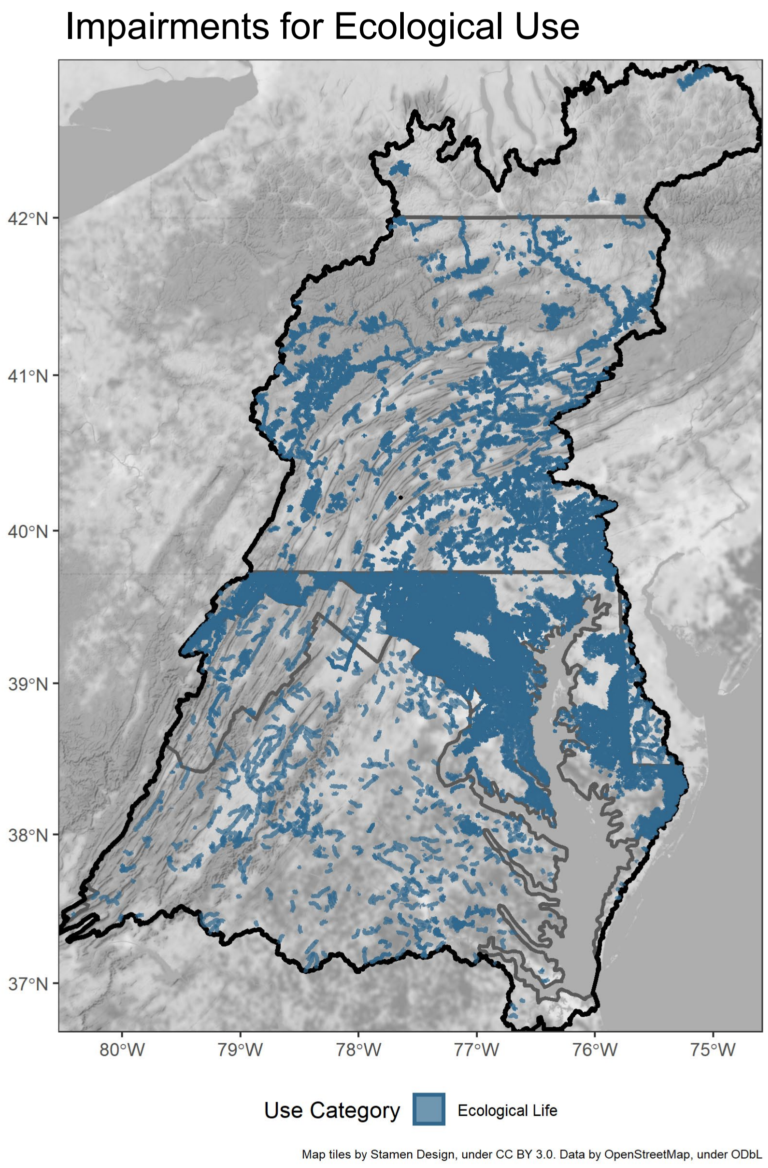
Ecological Use Impairments





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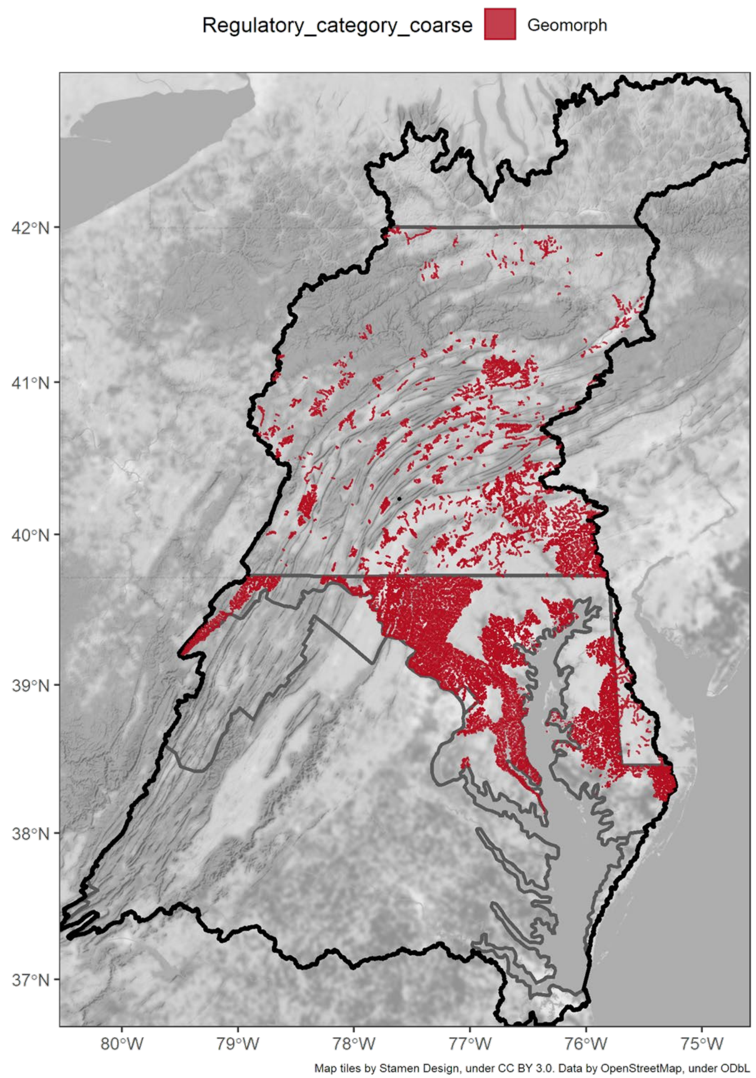
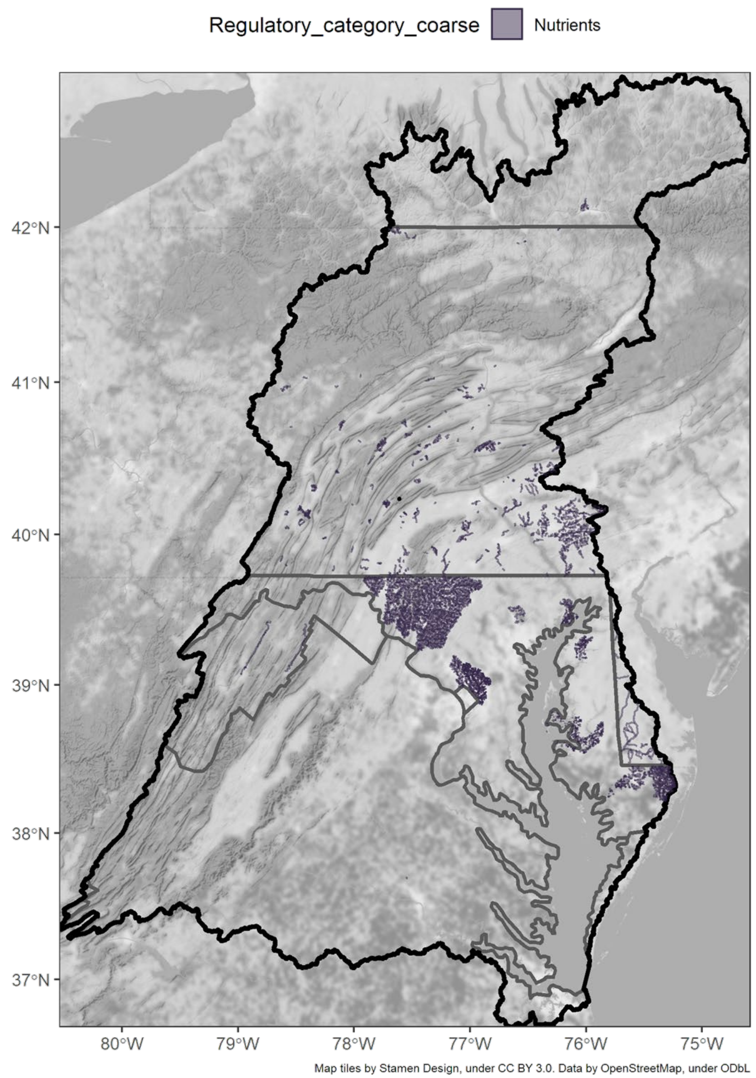
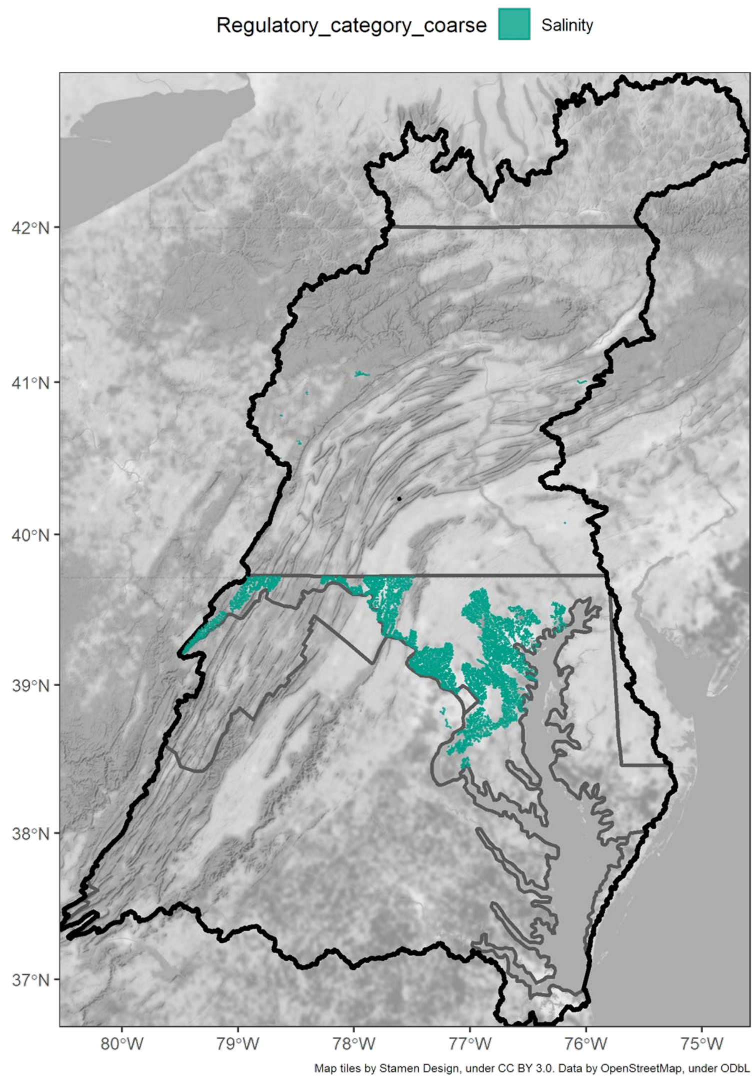
Stressor Impairment Maps – Ecological Use







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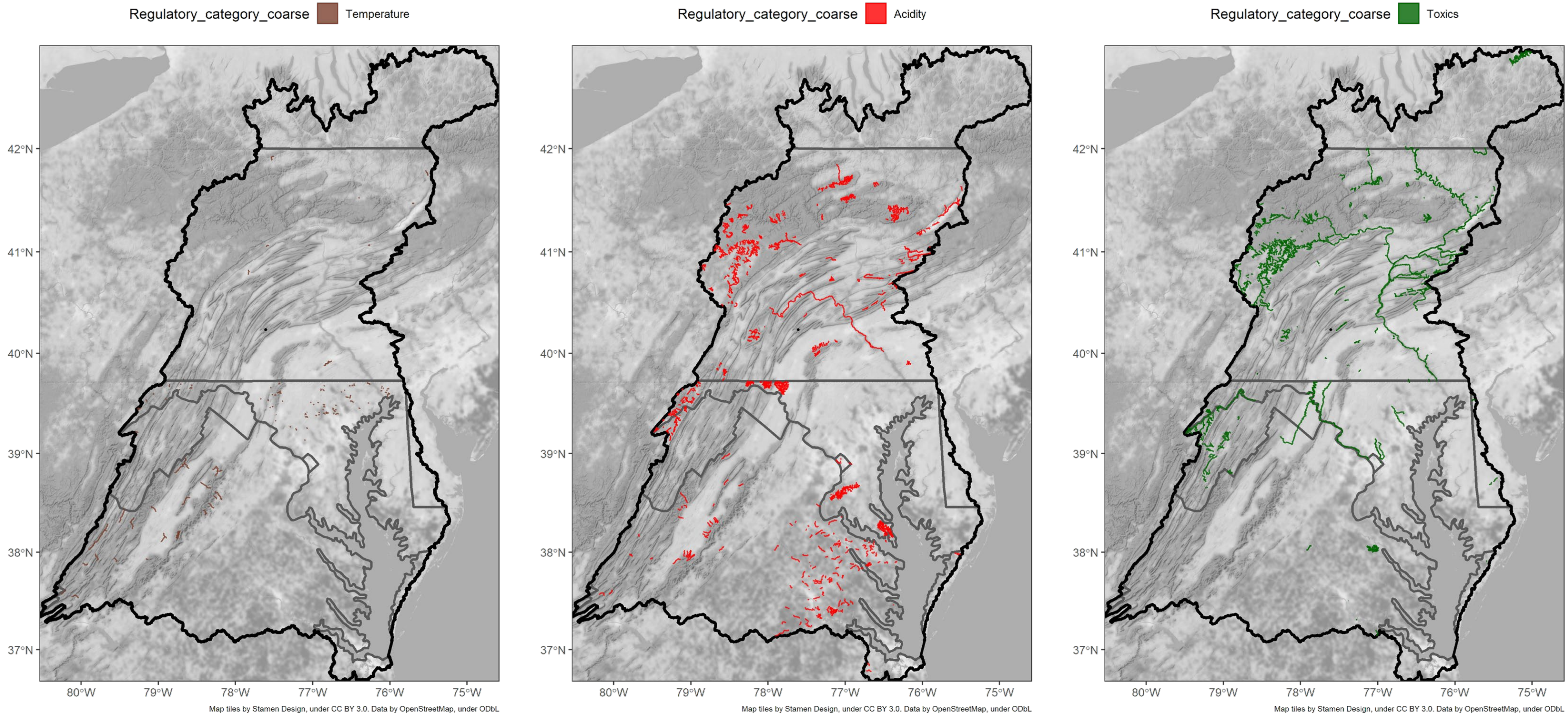

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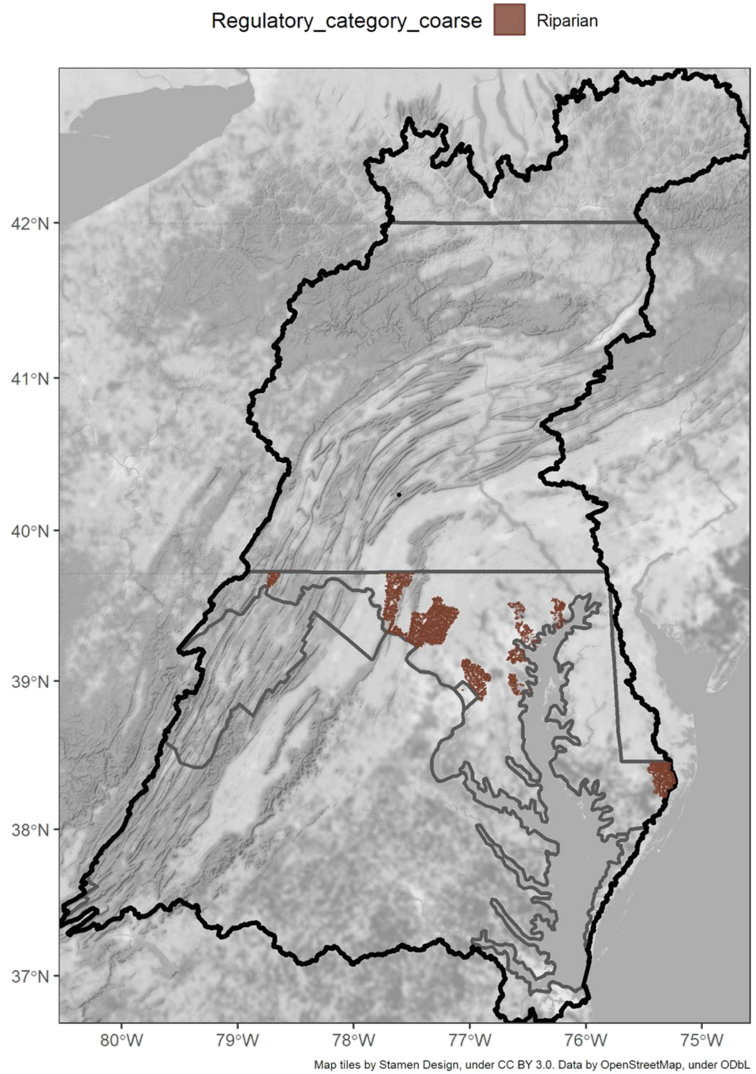
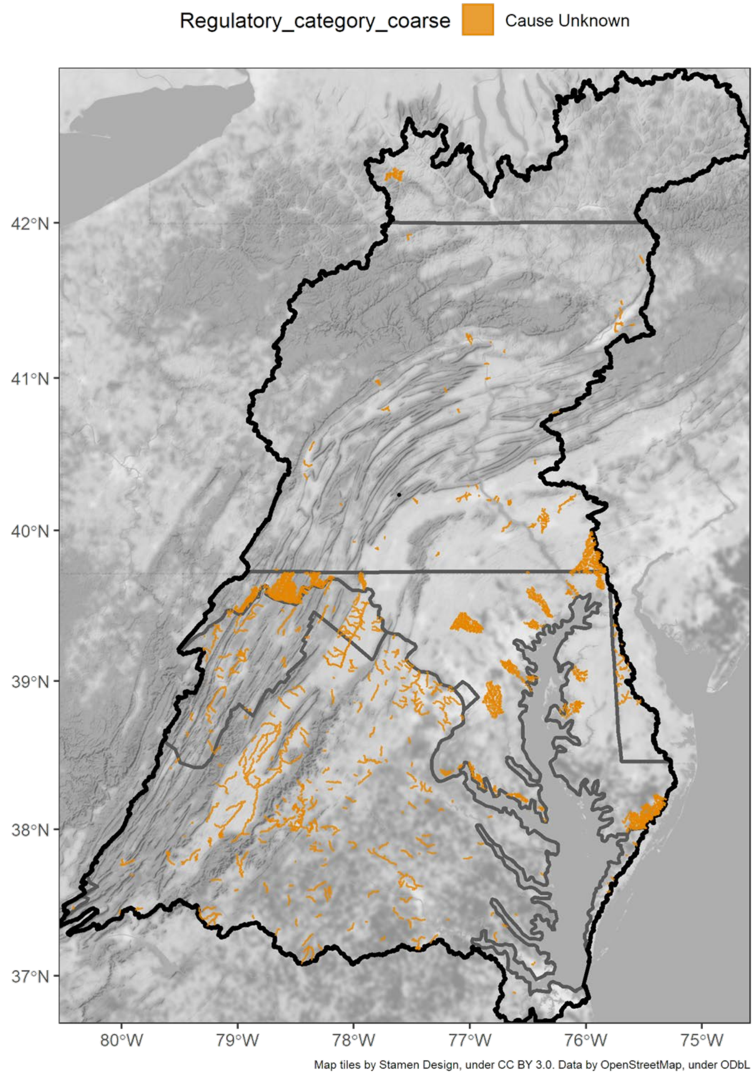
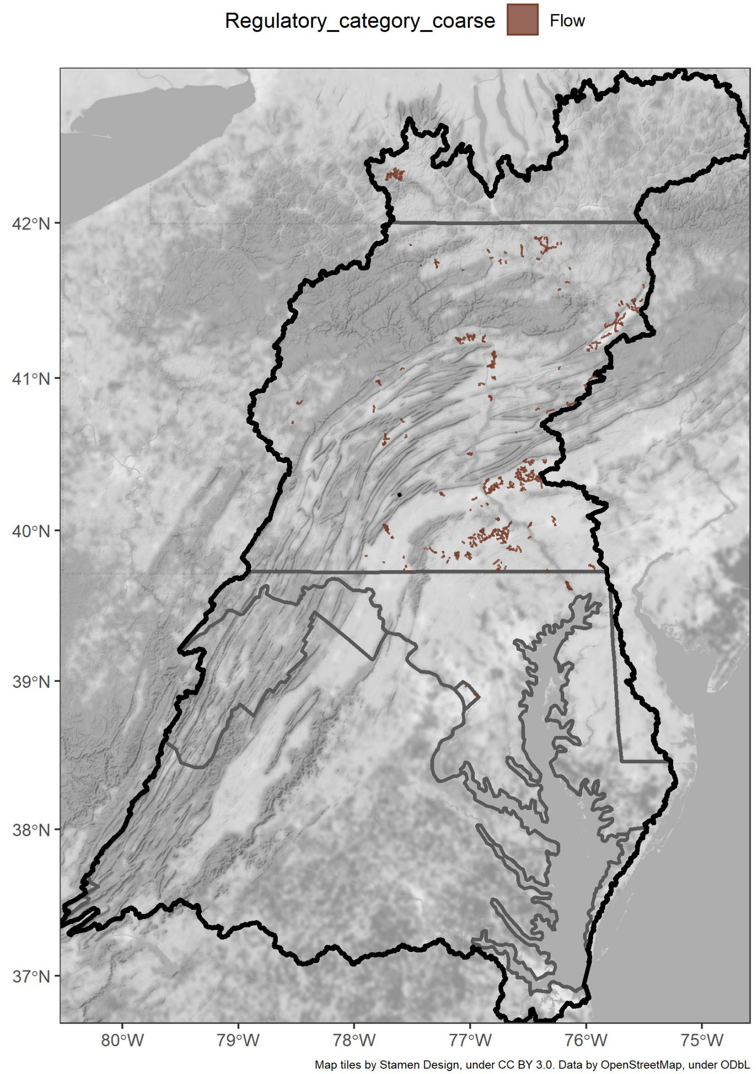




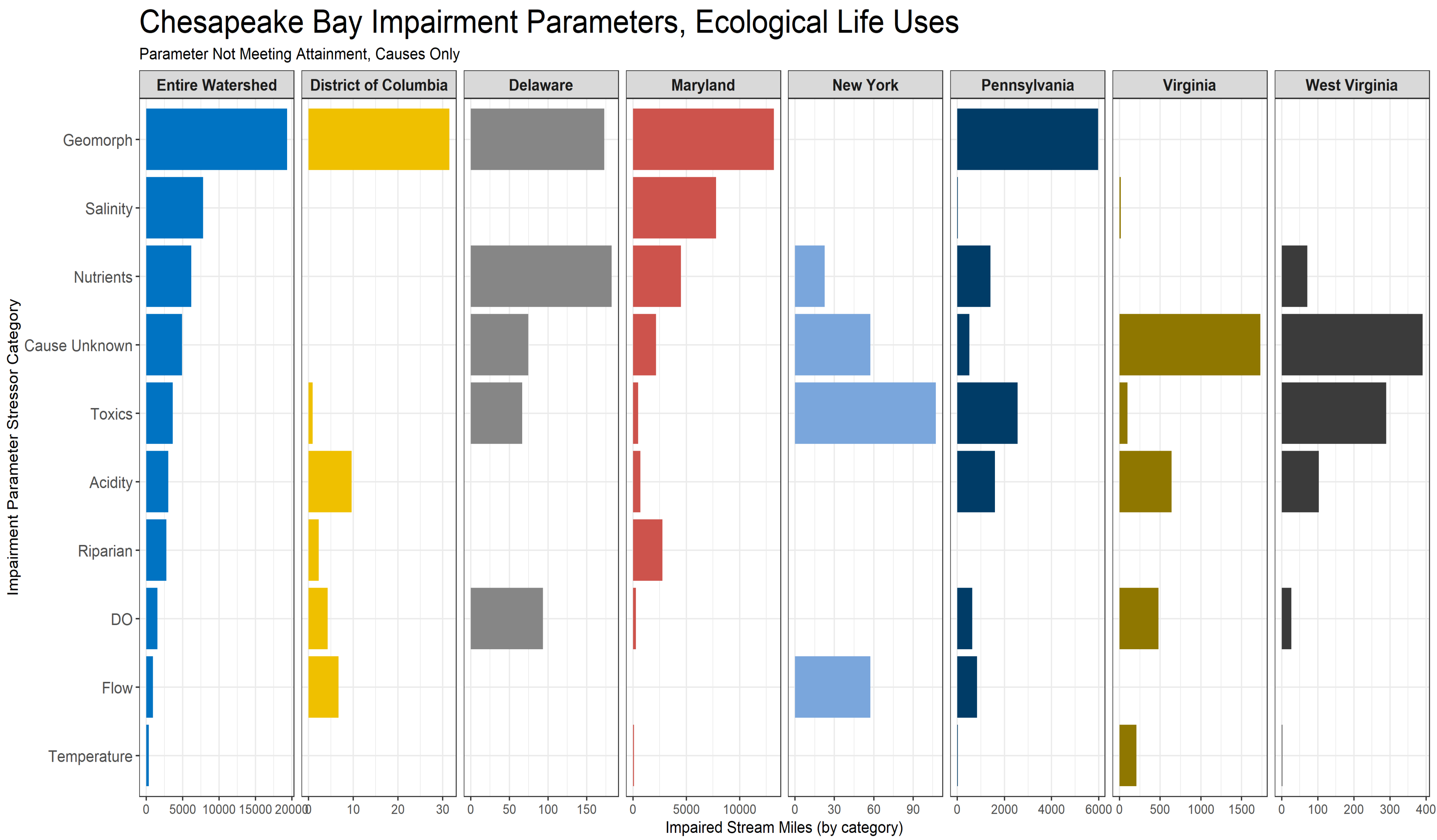


Provisional results, for feedback only

Most Frequent Stressors (Coarse)

Takeaways:

1. Sediment & physical habitat ("geomorph") most common impairment by mile
2. Salinity #2 by mile, yet driven almost exclusively by Maryland
3. Large overall differences in listings by State!
4. "Cause Unknown" is a common impairment for some states → data gap



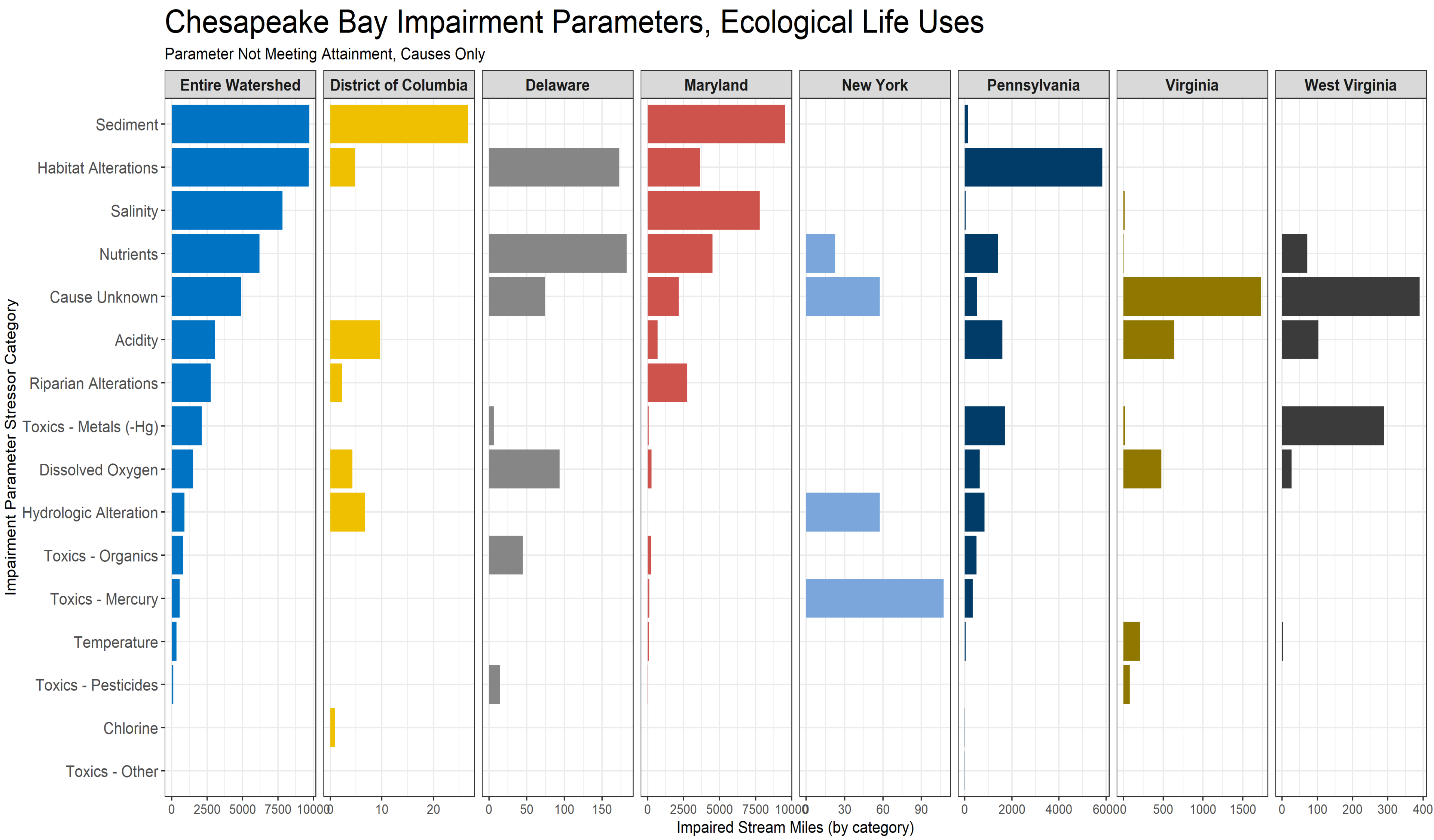
Provisional results, for feedback only

Most Frequent Stressors (Fine)

Takeaways:

1. Some states use "suspended sediment" some use "habitat impairment" (bed siltation)
   - ➢ Controlling sediment load, bank erosion, or riffle quality/ embeddedness are related, but management interventions do not affect these equally!

2. Toxic impairments are mainly metals, mercury in NY, current pesticide impairments are rare (n=4), legacy and legally banned



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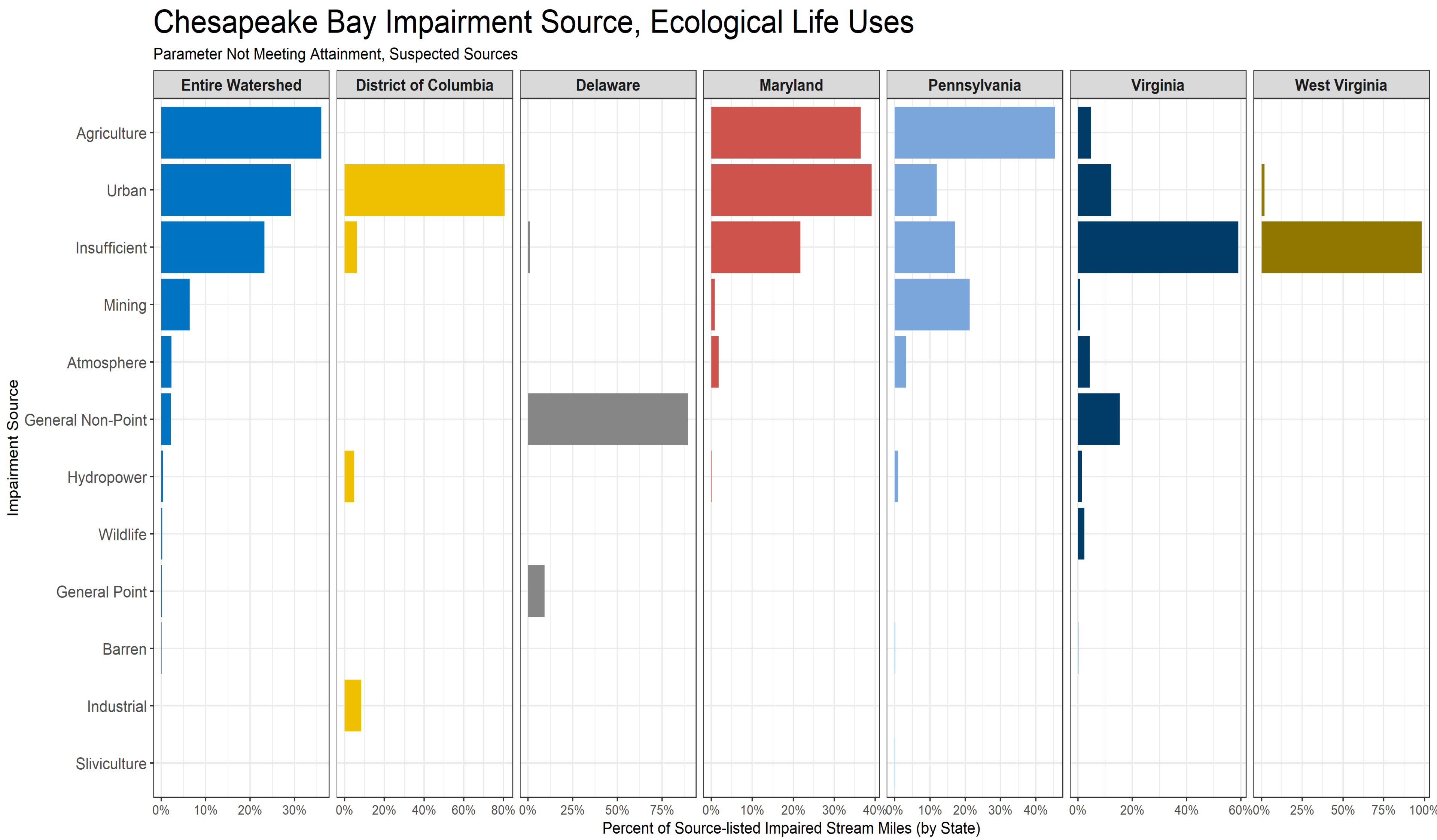
Most Frequent Drivers

Takeaways:

1. Most states do not provide sufficient information to derive landscape source of the impairment

2. Yet agriculture and urban-driven impairments are largely balanced across watershed

3. Large differences in response by state (Delaware: Point/non-point, Pennsylvania: Mining)



Provisional results, for feedback only

Preliminary study findings - Overall

1. **Toxic contaminants are very important but may be under-studied**
    - Pesticides were most important toxic grouping in literature
    - Metals most frequently reported in the ATTAINS dataset
2. **Salinity, geomorph, and nutrients are both important and pervasive**
    - Salinity = prevalent in urban and mining settings
    - Nutrients = prevalent in ag and urban settings
    - Geomorph = largely sediment-driven habitat issues
3. **Flow alteration is an important urban stressor but rarely measured**
    - Difficulties and expense associated with monitoring
4. **A more unified and holistic approach to stressor characterization and assessment methods is needed**
    - Adopt common language and conceptual understandings of driver-stressor-bio relationships and mechanistic pathways
    - Study design and assessment methodologies influenced by prior knowledge and state-defined uses
    - Key stressors vary based on how biological response is defined
    - State-level differences in monitoring, stressor identification methods, and reporting make regional comparisons complicated

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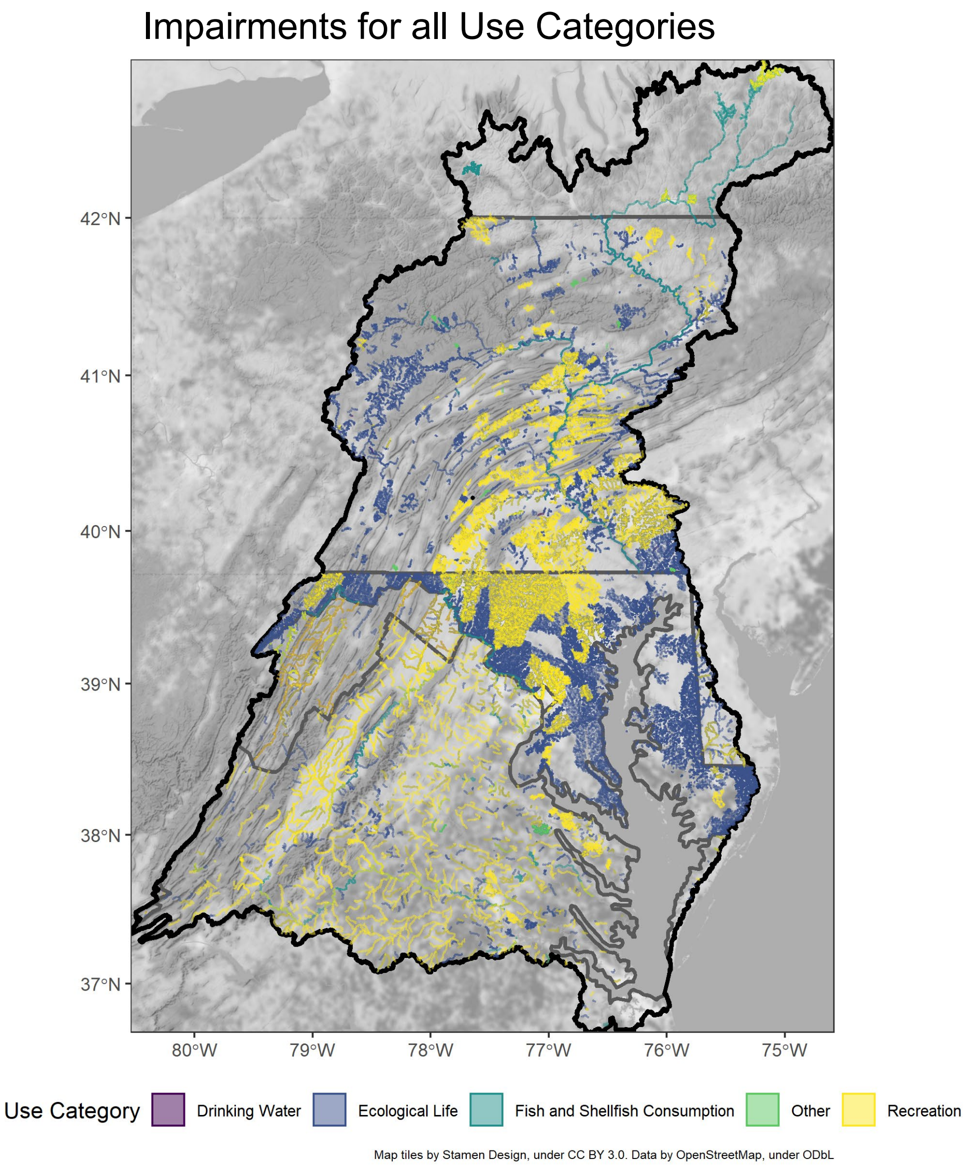
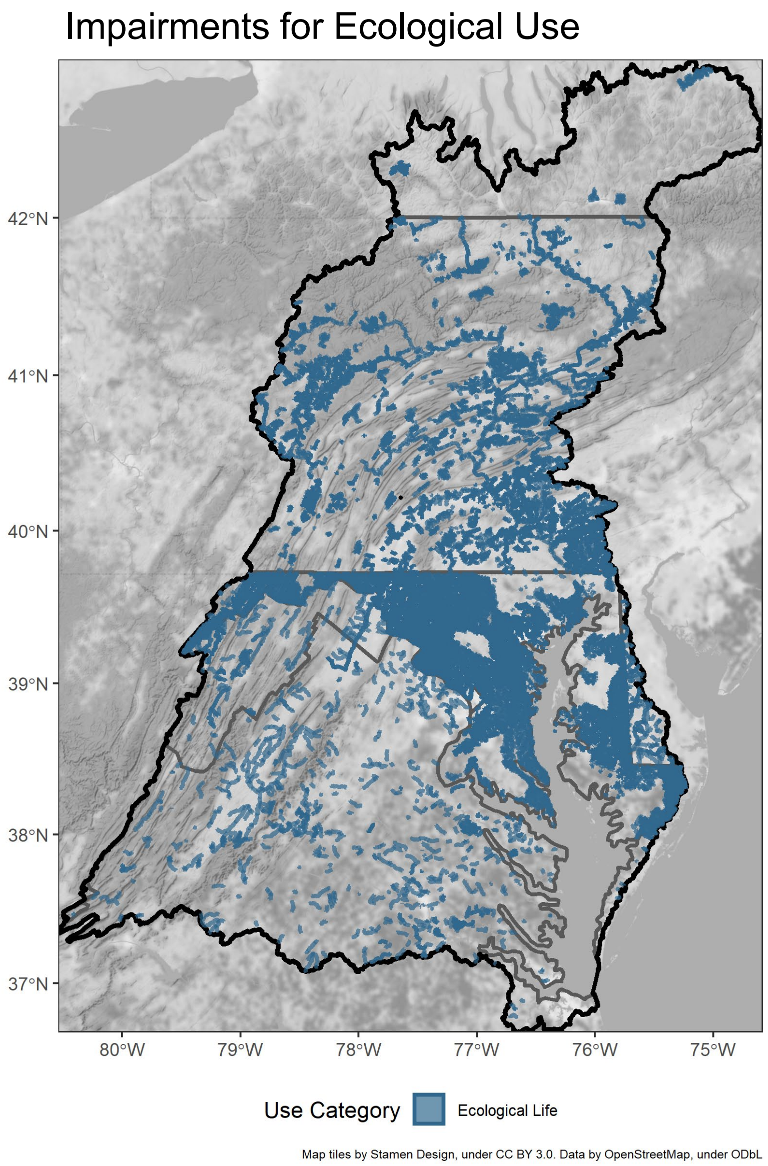
Ecological Use vs other uses





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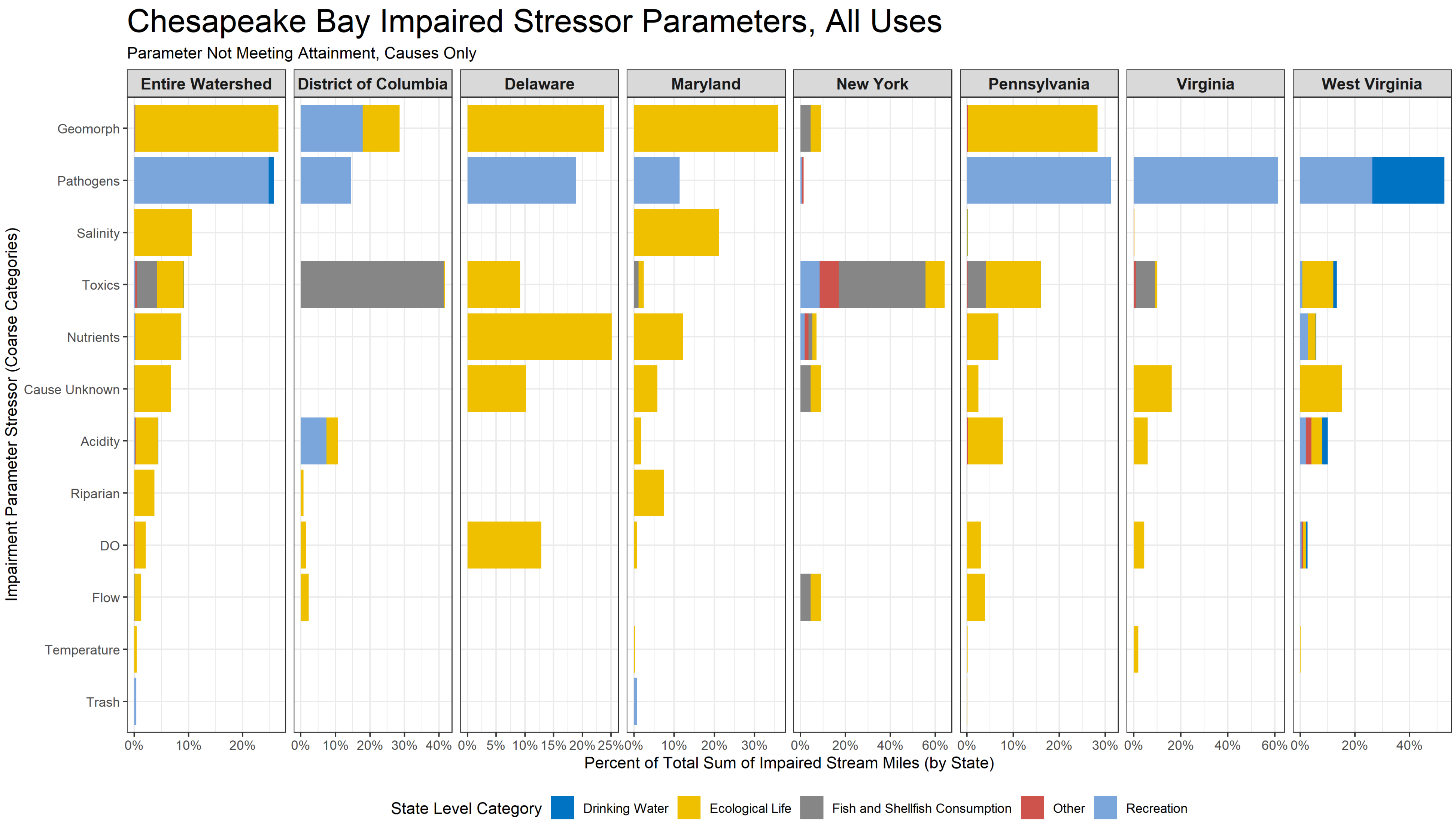
Most Frequent Stressors (Coarse) - All Uses

Takeaways:

1. Patterns different by state – 80% of impairments in VA are attributed to Pathogens
   - Yet bacteria impairment due to cattle would likely co-occur with unlisted sediment or nutrient issues!

2. Some stressors split across several use categories
   1. Toxics
      1. New York, DE, DC
   2. Sediment & Geomorph:
      1. Ecological Use vs
      2. Consumption vs
      3. Recreation



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Most Frequent Stressors (Fine) - All Uses

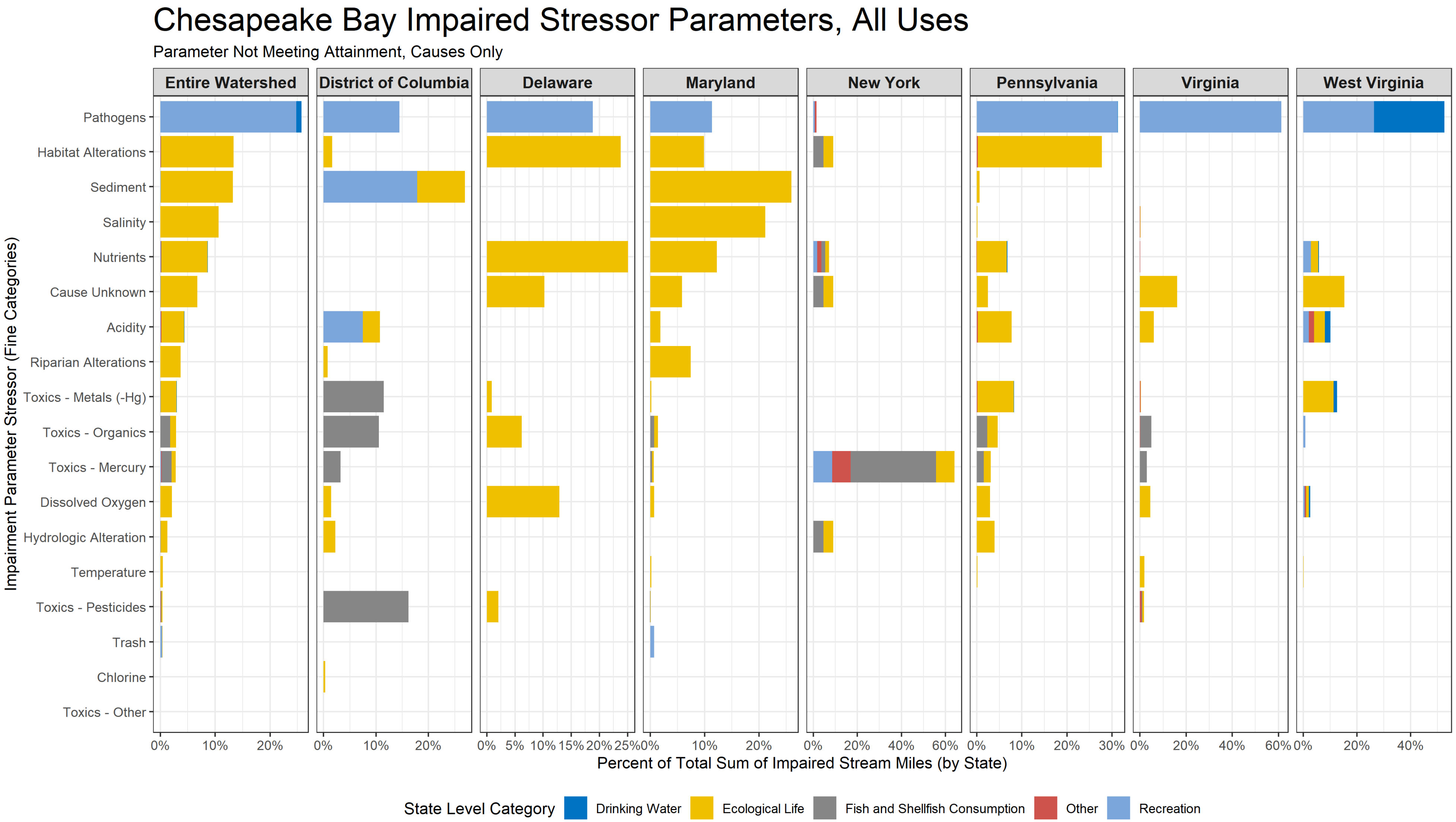
Takeaways:

1. Pathogens (i.e. bacteria) are #1 fine-category impairment, predominantly due to Recreational Uses

2. Toxic impairments are predominantly Metals, Organics, Mercury, yet very rarely Pesticides

3. Patterns by stressor and usage category vary heavily by jurisdiction

4. But most stressor parameters are listed under Ecological Use



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Toxic Impairments – Uses & Sub-Categories

Takeaways:

1. Is toxic impairment for one use directly relevant to other uses?
   - Is impairment for recreation meaningful for fish and shellfish consumption?
   - Is impairment for fish and shellfish consumption meaningful for ecological life/stream health?

2. State-differences in reporting causes more confusion
   - E.g., toxic contaminants in recreational fisheries being listed for ecological life OR fish consumption OR recreation, depending on state

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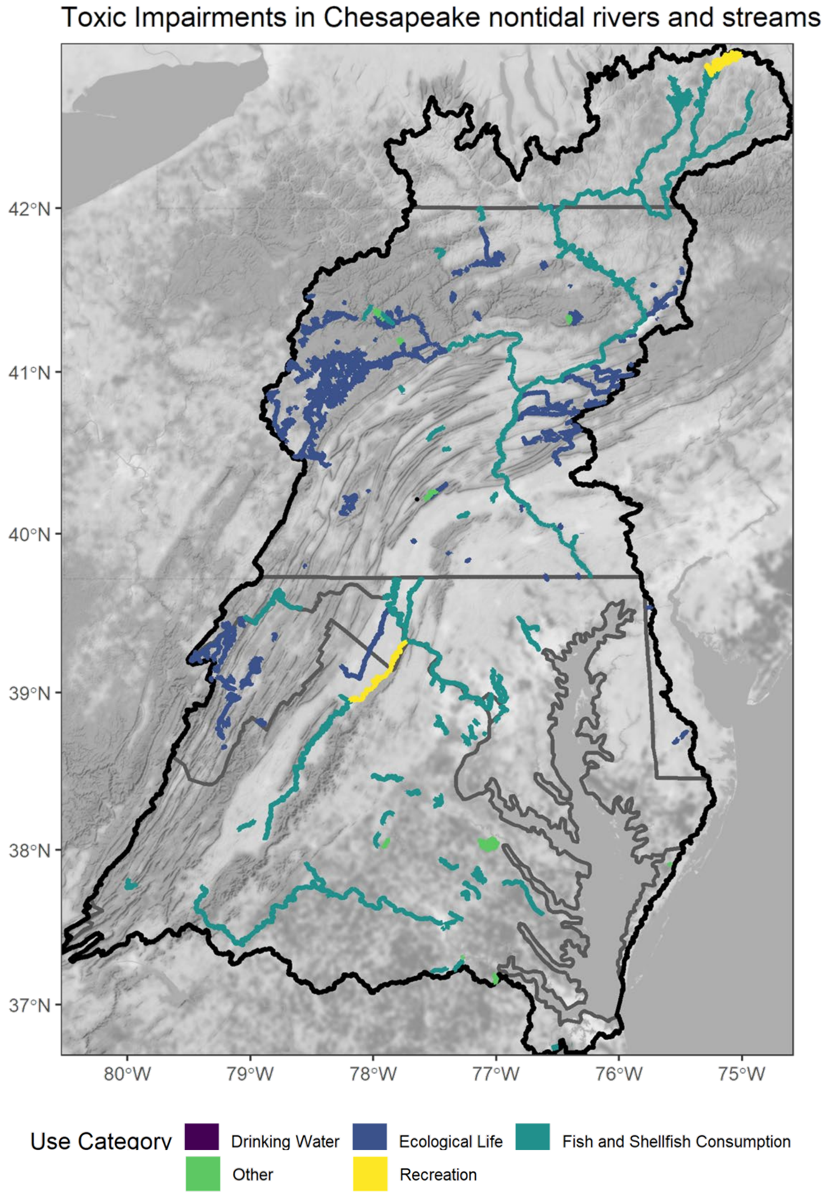

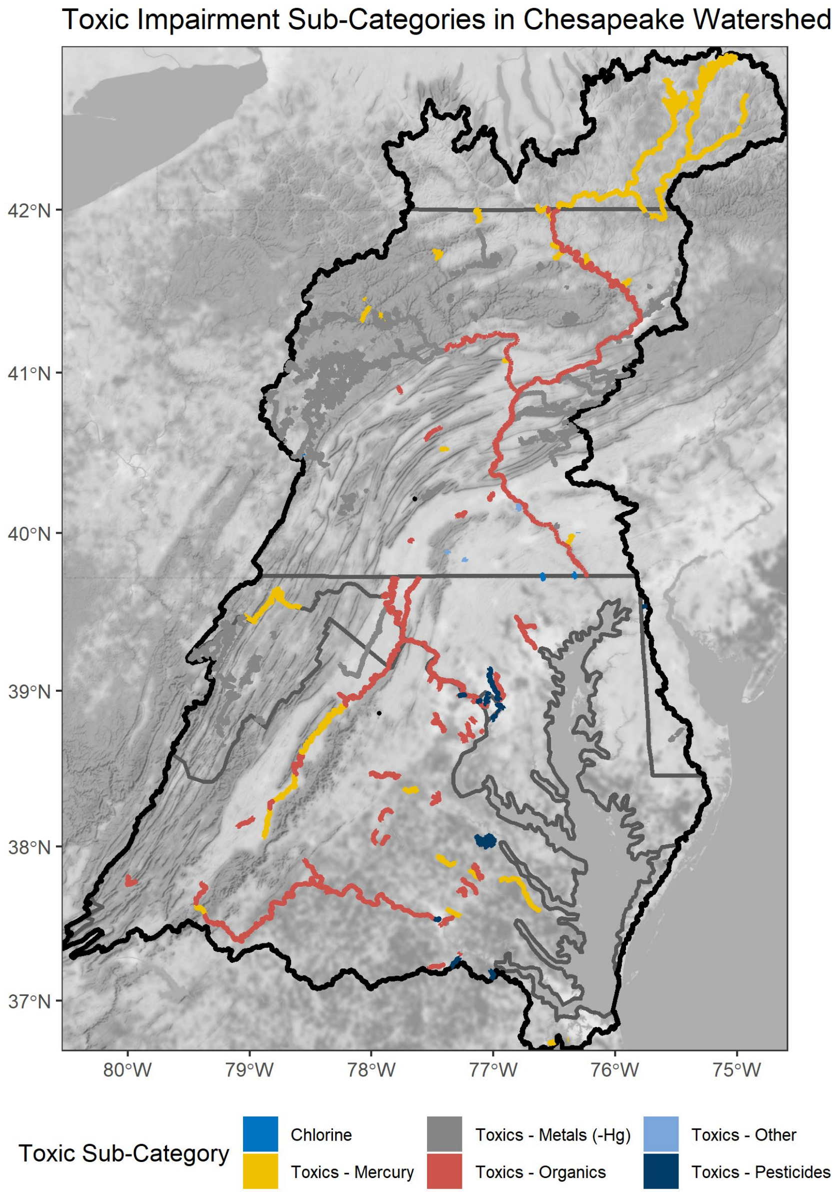

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EXTRA SLIDES

Stressor frequency analysis results

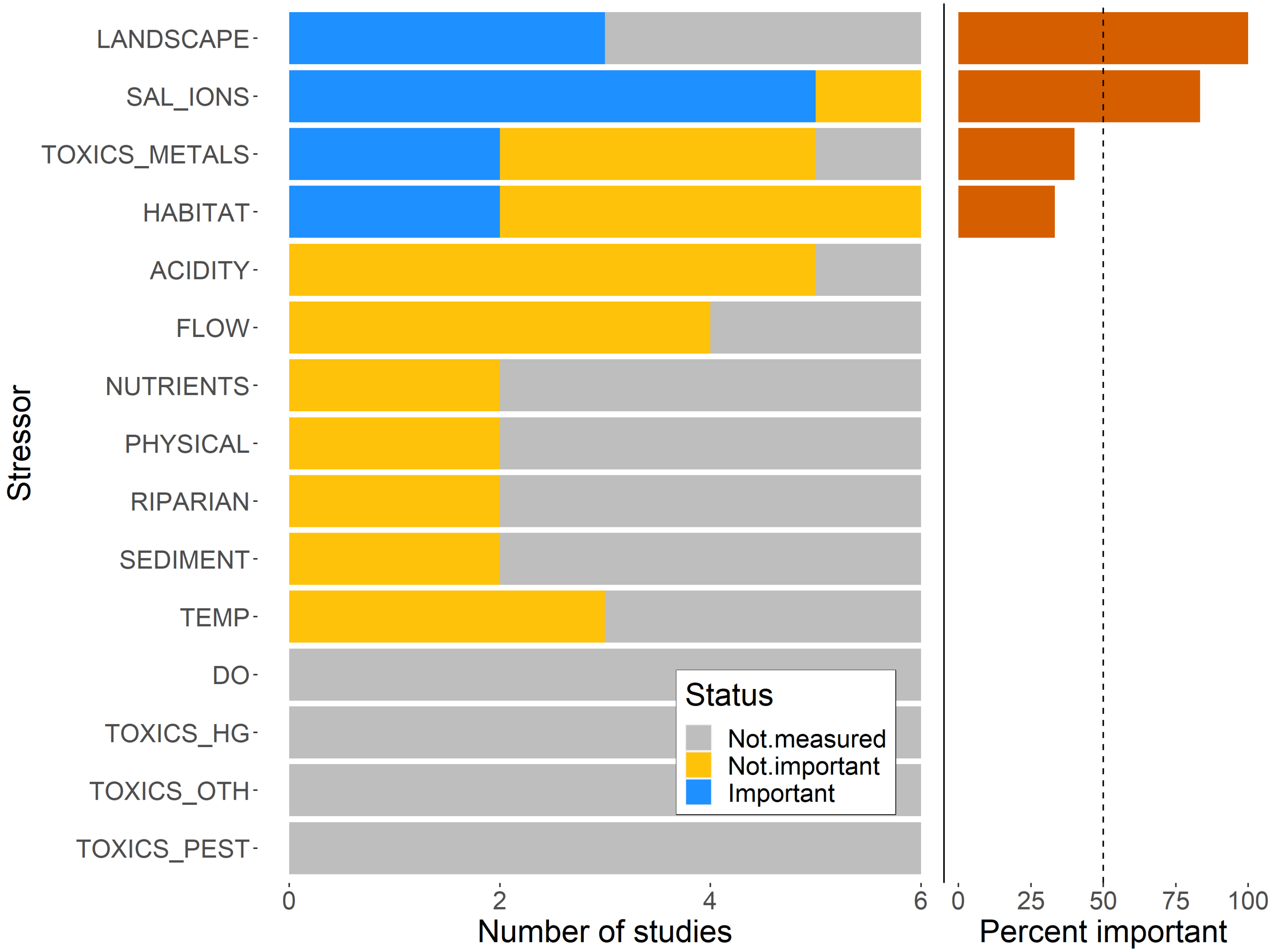
Mining studies (n = 6)

Key findings

1. Landscape factors (e.g., coal production, % watershed mined) and salinity/ions important in > 50% studies

2. Metals and habitat often measured but not often reported as important

3. pH, flow, temperature, and nutrients not reported as important



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Stressor frequency analysis results

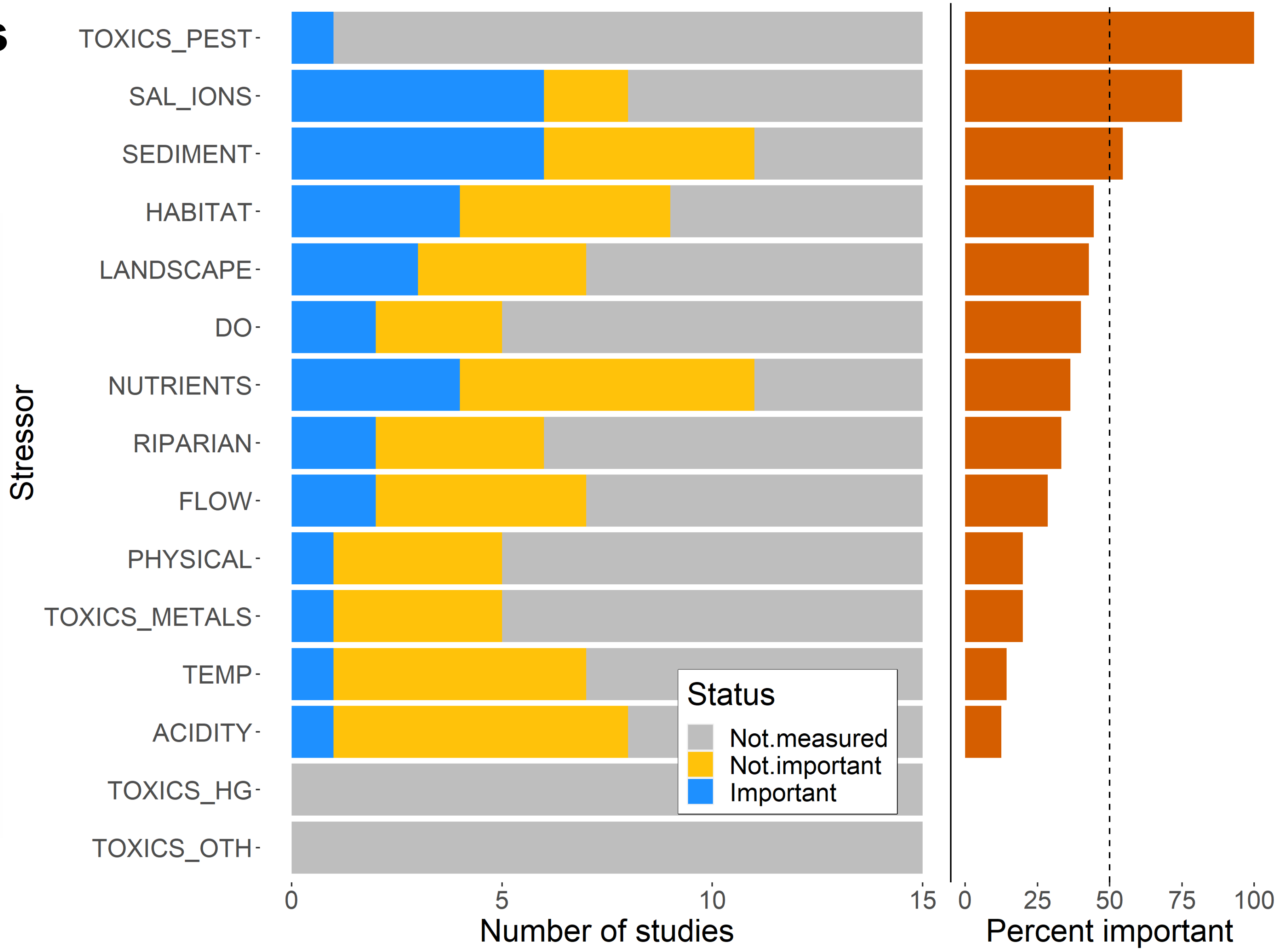
Studies using EPT richness as response variable (n = 15)

Key findings

1. Toxics, salinity/major ions, and sediment were important in > 50% of studies

2. Toxics (pesticides, organics) were rarely measured

3. Temperature, flow and pH were rarely reported as important



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Stressor frequency analysis results

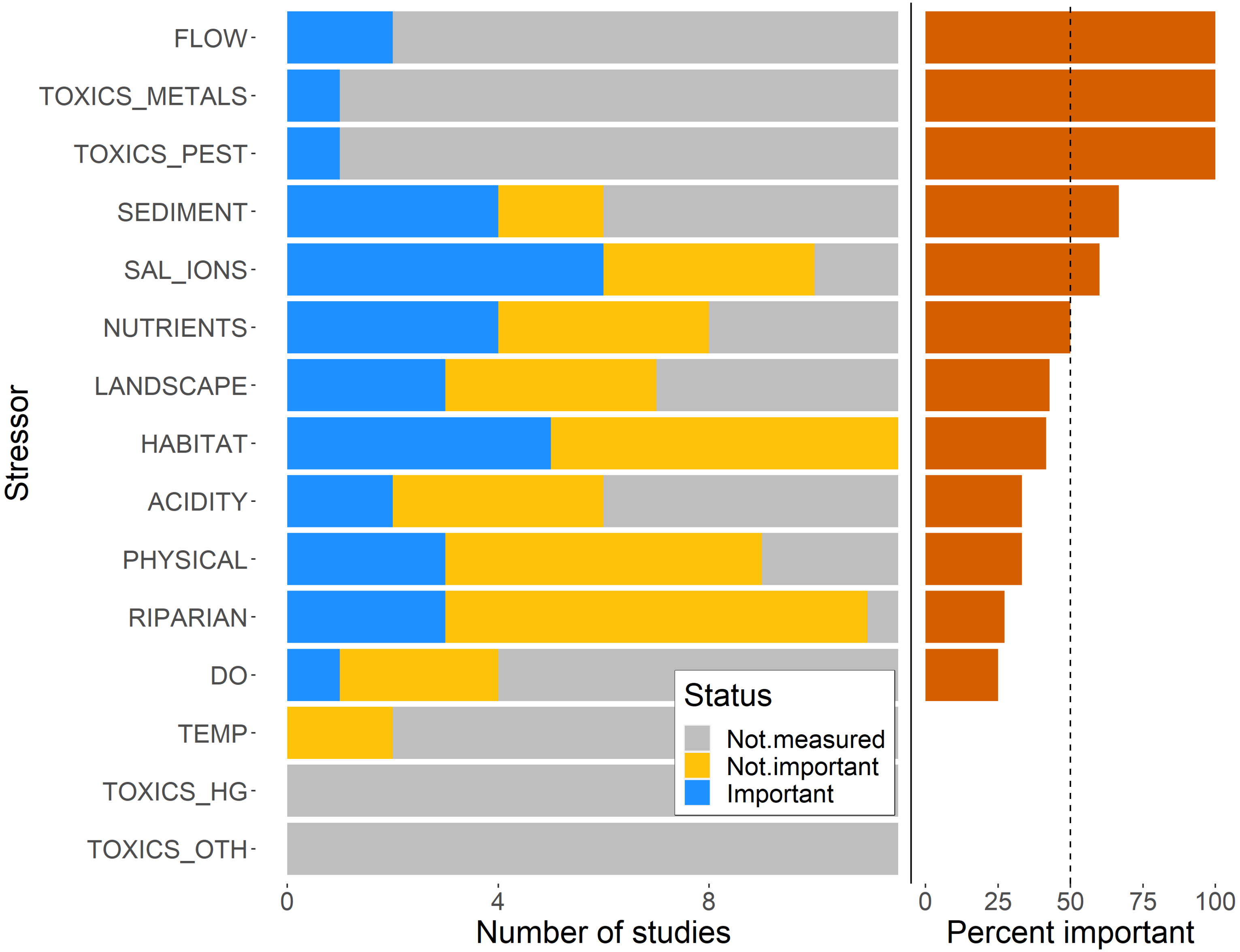
Studies using a multi-metric index as response variable (n = 12)

Key findings

1. Flow, toxics, salinity/major ions, and sediment were important in > 50% of studies

2. Habitat measured in all studies but important in < 50%

3. Watershed and riparian characteristics often measured but rarely important



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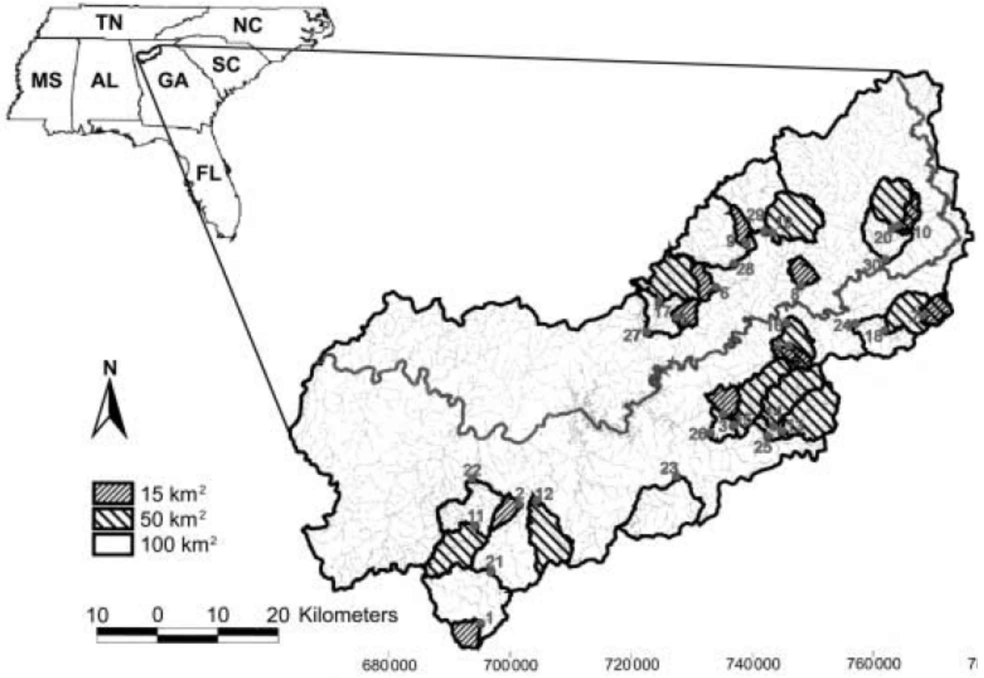
Salinity is key stressor in urban study



Stream macroinvertebrate response to catchment urbanization (Georgia, U.S.A.)

Roy and others 2003 (*Freshwater Biology* 48: 329–346)

- **Study design**: 30 sites along urbanization gradient
- **Other stressors measured**: Landscape, riparian, geomorph (physical habitat and TSS), nutrients, DO, acidity
- **Analysis:** Multiple linear regression
- **Response variables:** Multiple

	Adjusted R^2	Partial R^2	P	Independent variables
Total richness	0.69	0.40	<0.001	+ *Phi* variability
		0.25	<0.001	– Specific conductance
		0.07	0.020	+ Depth
Total density	0.50	0.40	<0.001	+ *Phi* variability
		0.13	0.012	– Specific conductance
EPT richness	0.66	0.52	<0.001	– Specific conductance
		0.12	0.018	+ *Phi* variability
		0.06	0.042	+ Depth
B-IBI	0.50	0.51	<0.001	– Specific conductance
ICI	0.78	0.60	<0.001	– Riffle *phi*
		0.15	<0.001	– Specific conductance
		0.05	0.015	+ *Phi* variability
NCBI	0.36	0.27	0.008	– Specific conductance
		0.13	0.023	– Turbidity
FBI	0.18	0.13	0.013	– Specific conductance

Table 5

- All biological response variables declined with increasing specific conductance
- Could be direct effect of conductivity or “as a surrogate ‘chemical signal’ from increased non-point sources in the catchments”

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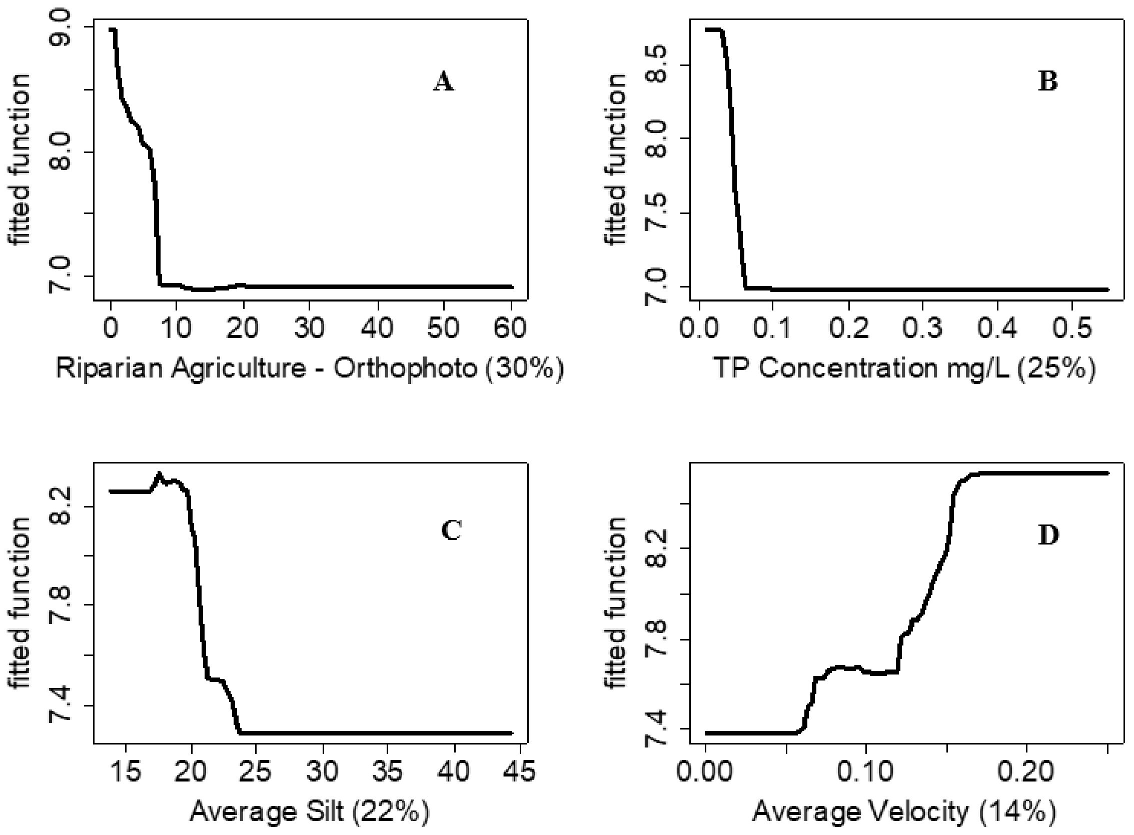
Habitat is key stressor in agricultural study



**Results from Eastern region model (includes Delmarva and Georgia Coastal Plain)*

Agricultural disturbance response models for invertebrate and algal metrics from streams at two spatial scales within the U.S.

Waite 2014 (*Hydrobiologia 726:285–303*)

- **Study design**: Eastern region- 54 sites along agricultural intensity gradient
- **Other stressors measured**: Landscape, riparian, habitat, nutrients, DO, and stream temperature
- **Analysis:** Boosted regression trees
- **Response variables:** EPT richness, Observed vs expected taxa, tolerant taxa richness

<u>Top stressors in Eastern region for EPT richness</u>

- Percent ag in riparian buffer (riparian)
- TP concentration (Nutrients)
- **Average silt (Geomorph-habitat)**
- **Ave velocity (Geomorph-habitat)**
- TN concentration (Nutrients)

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Stressor lit review analysis methods

Multi-stressor studies (n=78) → Multi-stressor studies selected for further analysis (n=65)

- Examined each study's statistical analysis
- Determined study was eligible if:
  1. Stressor-bio relationships were quantified
  2. Appropriate statistical approaches were applied and reported
     - Examples = multiple linear regression, multivariate analysis, machine learning techniques (BRT)
     - Correlations were included if alpha and/or p-values were reported

NARRATIVE SUMMARY

- Did not relate stressor to biological response (n=20)
- Insufficient statistical analysis or reported stats (n=11)

Sufficient stats for use in lit review analysis (n=34)

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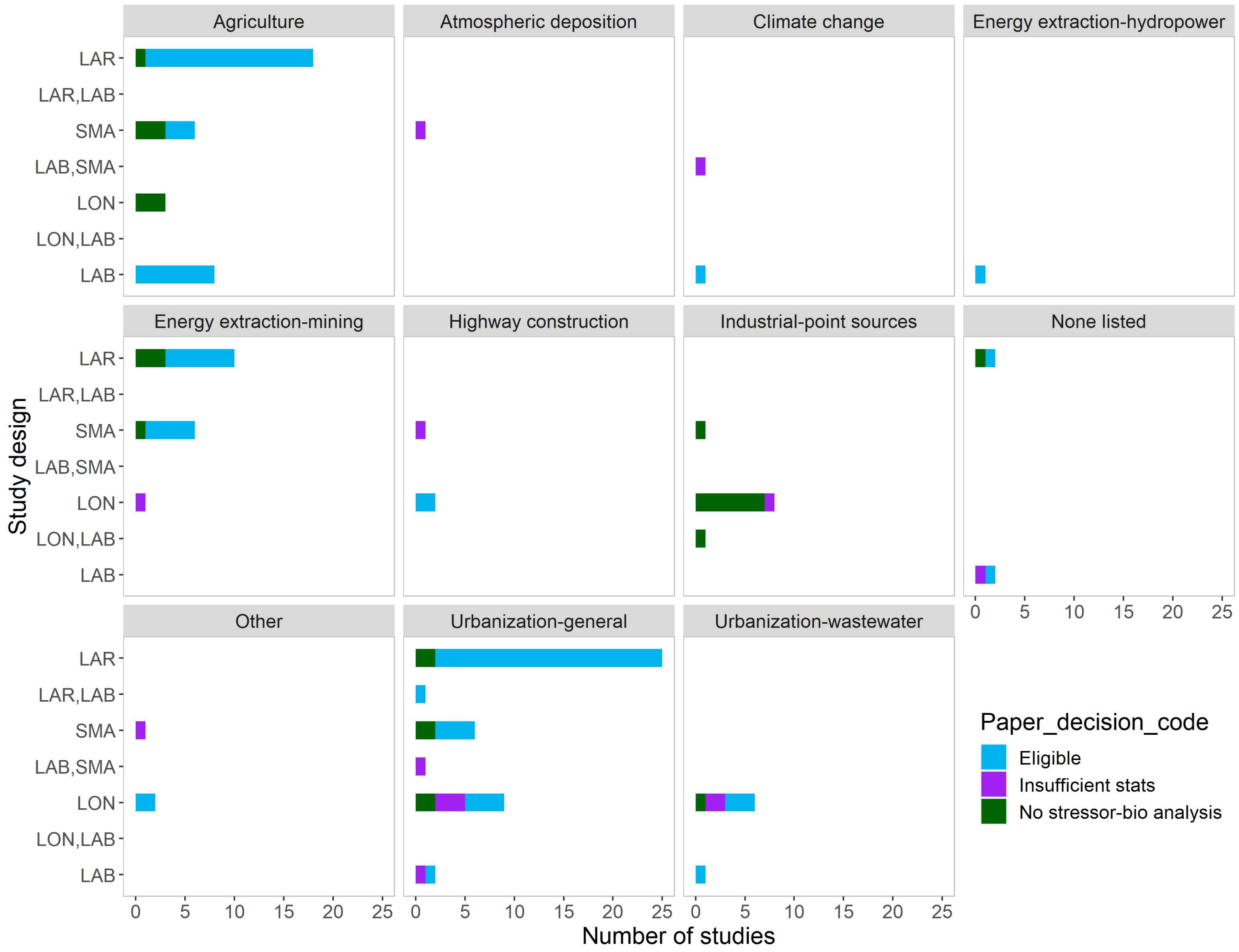
Study eligibility for lit review analysis



<u>Study design definitions</u>

LAR = Large study (15+ observations units)
SMA = Small study (<15 observations units)
LON = Longitudinal study along one stream
LAB = Laboratory, flume, or mesocosm study

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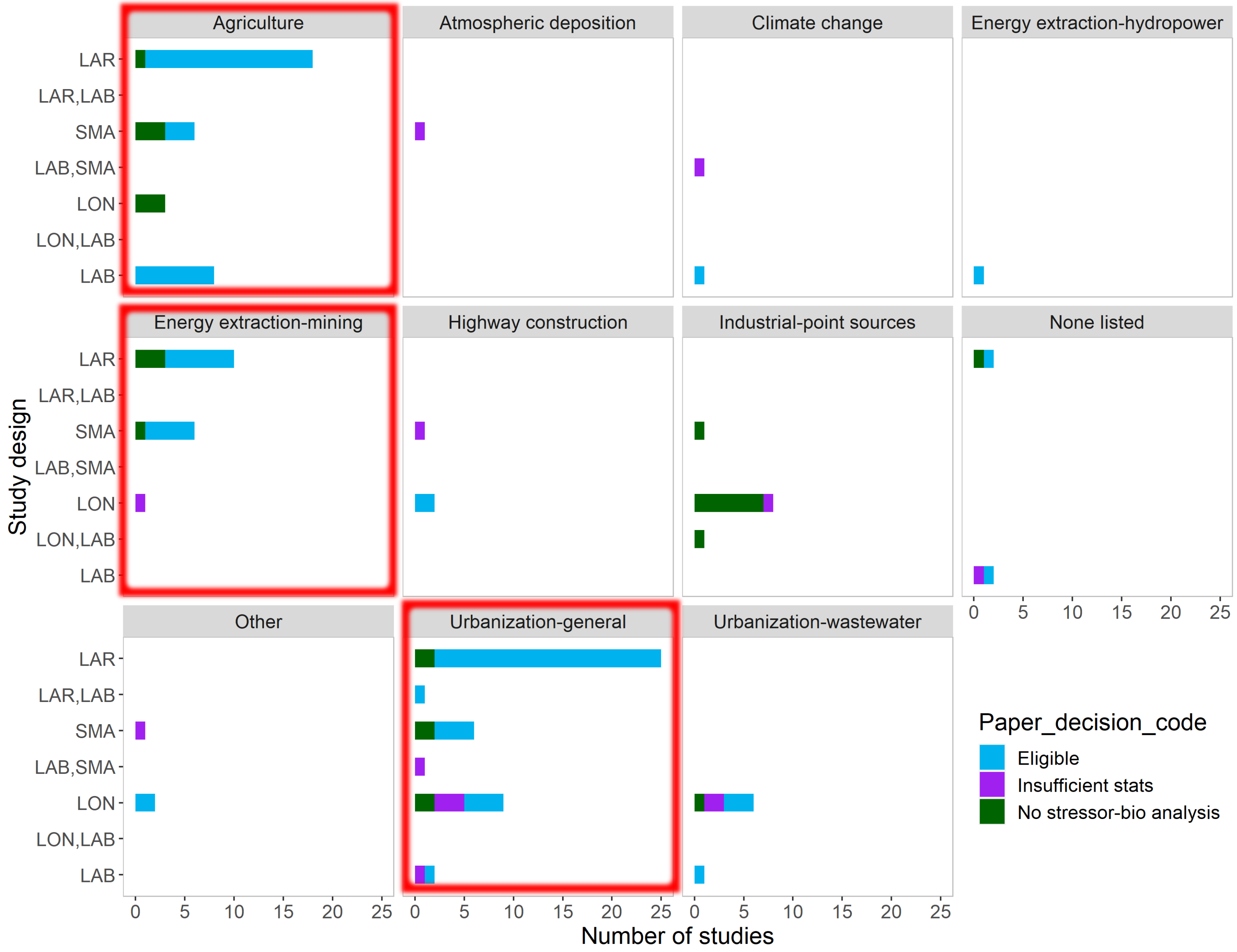
Study eligibility for lit review analysis

Which studies were eligible?

- Most large studies
- Most studies that focus on agriculture, urbanization, and mining



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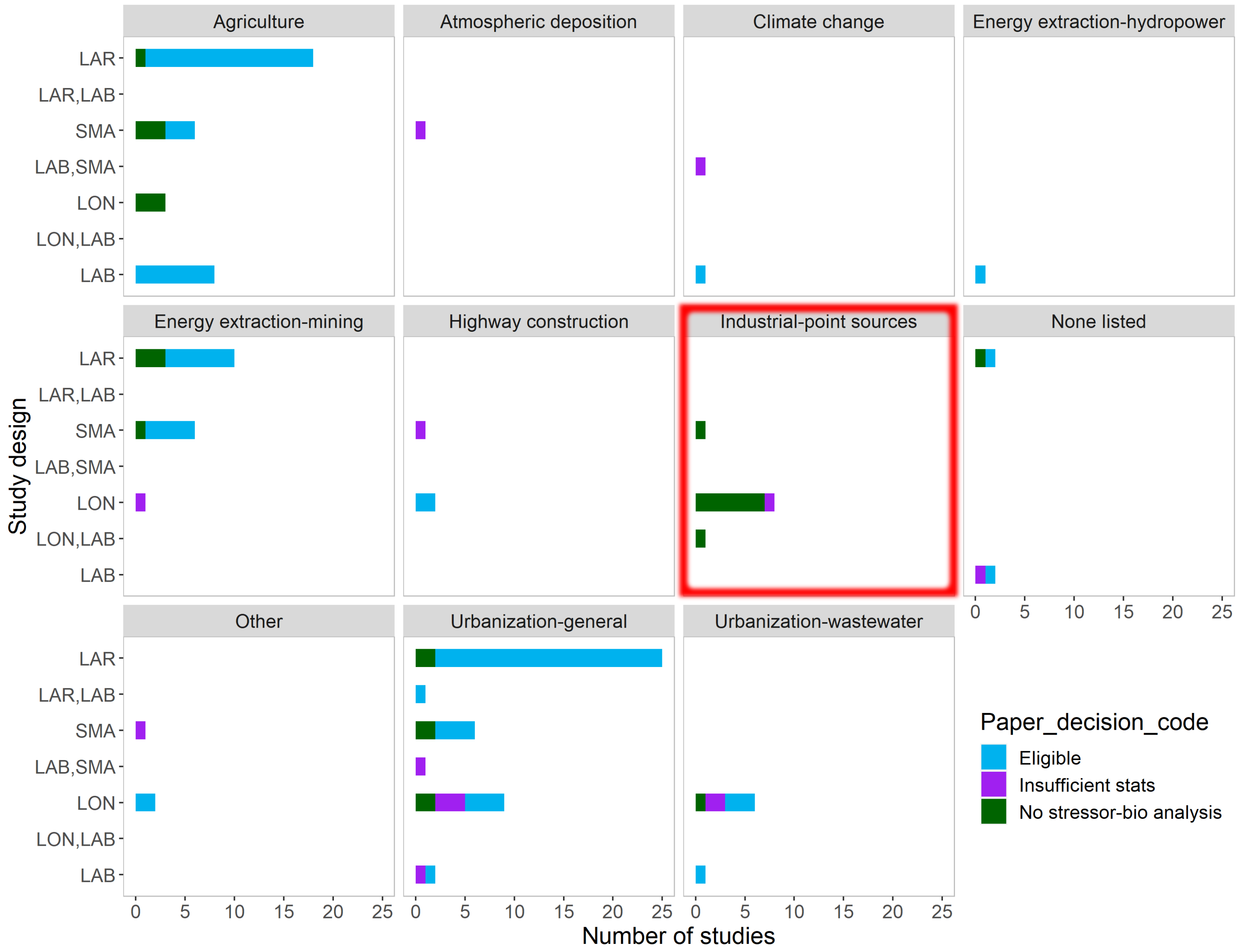
Study eligibility for lit review analysis

Which studies were eligible?

- Most large studies
- Most studies that focus on agriculture, urbanization, and mining

Which studies were not?

- Many longitudinal studies
- Point source studies
- Some smaller studies



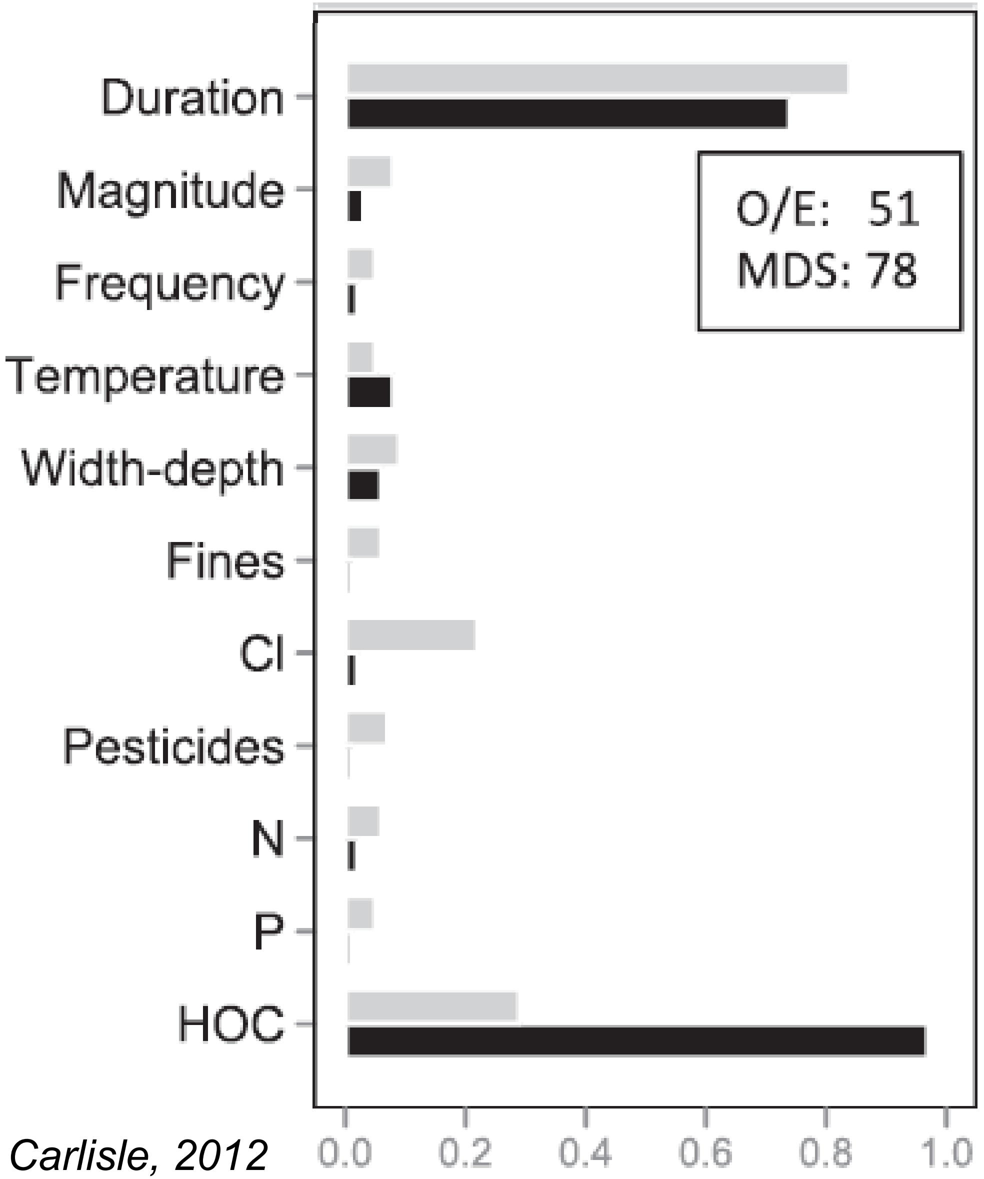
Study design definitions

LAR = Large study (15+ observations units)
SMA = Small study (<15 observations units)
LON = Longitudinal study along one stream
LAB = Laboratory, flume, or mesocosm study

Provisional results, for feedback only

Stressor frequency analysis methods

- Extracted stressor measurements that were found to be significant/important based on study's statistical analysis
  - Binary importance (Yes/No), not ranked
- Reported additional response variables separately
- Coarsened stressor measurements into general categories
  - Compared list of stressors reported as important to stressors measured
- Included some additional factors if included in a study's statistical analysis



Bryant and Carlisle, 2012