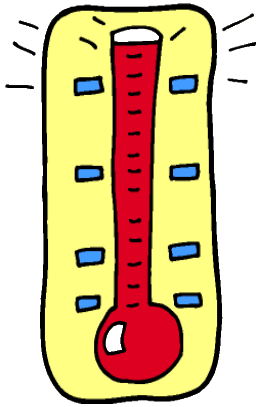
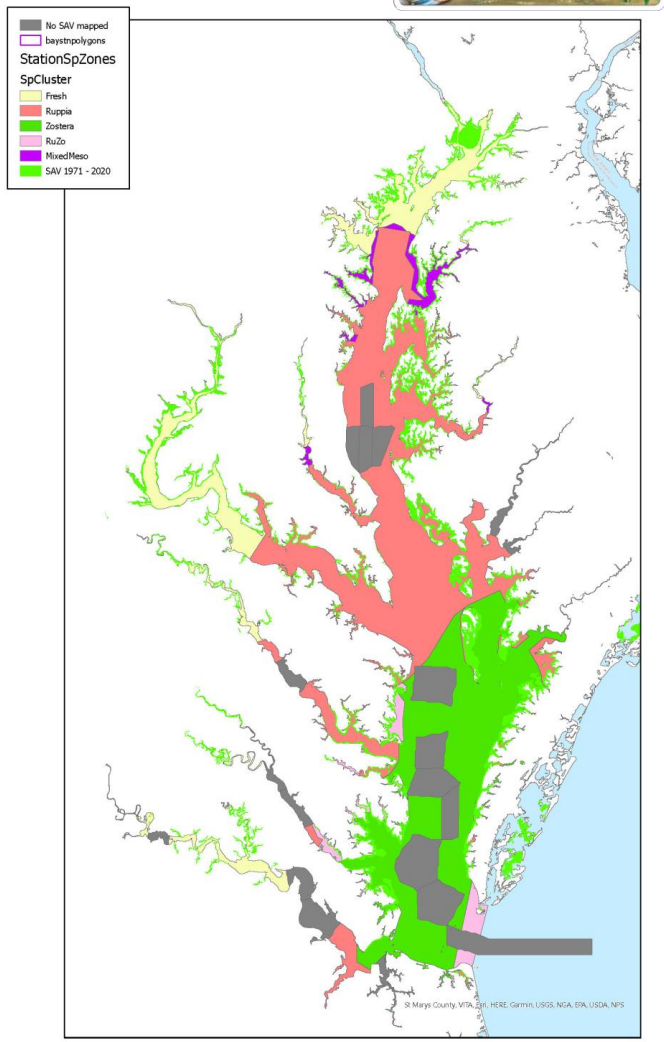
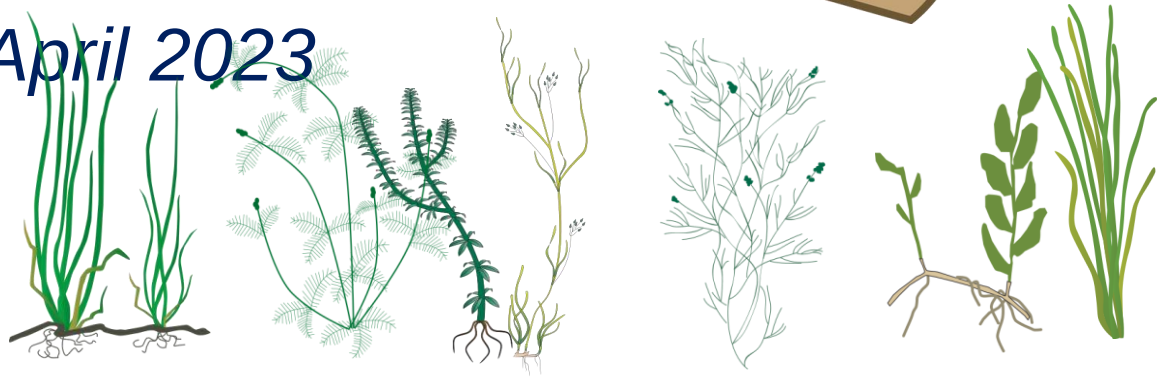
Envisioning the future for Chesapeake Bay SAV under climate change

Marc Hensel
Chris Patrick
Dave Wilcox
Jon Lefcheck





CBP Modeling WG April 2023

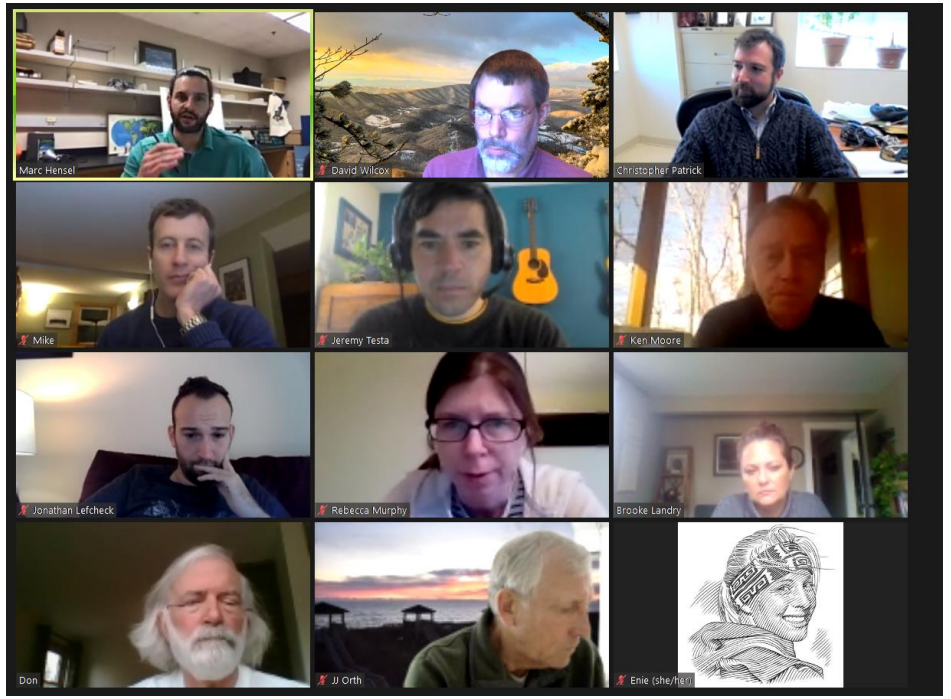


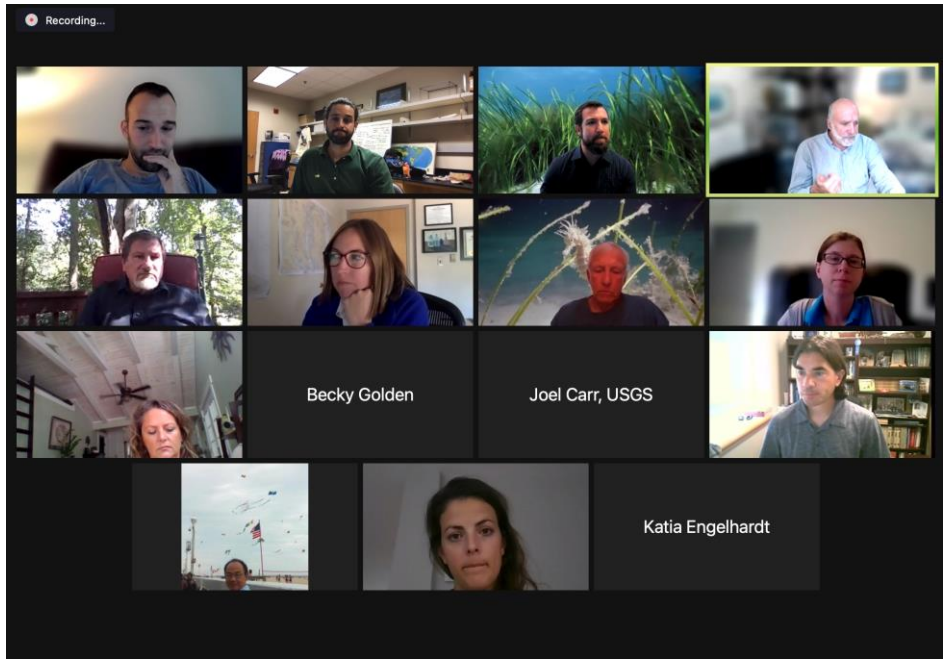
VIMS | William & Mary
Virginia Institute of Marine Science

THANKS to our steering committee!

J.J. Orth, Bill Dennison, Rebecca Murphy, Jeremy Testa, Matt Fitzpatrick, Katia Engelhardt, Cassie Gurbisz, Karen McGlathery, Aaron Kornbluth, Joel Carr, Lewis Linker, Kathrynlynn Theuerkauf, **Becky Golden & Brooke Landry**

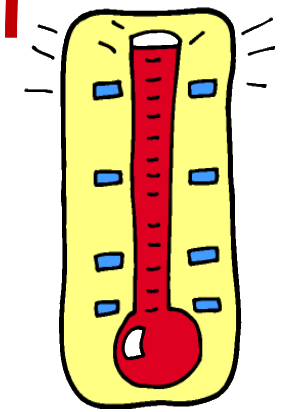
Richard Tian
IAN media library





How will climate change and human activities affect the major communities of seagrass and aquatic vegetation in the Chesapeake Bay?

Climate change



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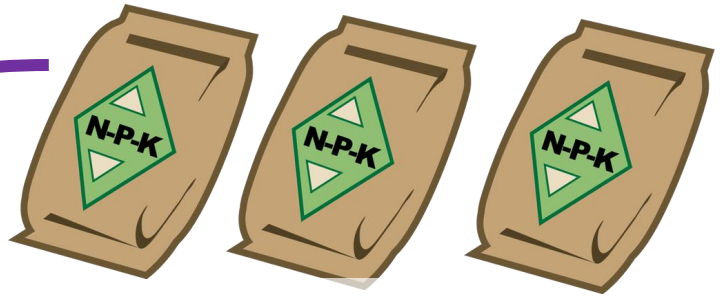
Temperature rise

Rainfall increased volume & intensity

Human activities



No further nutrient reductions

OR

More nutrient reductions

Predicting the future in three steps

Step 1	How have past environmental conditions affected seagrass and aquatic plant communities?
Step 2	How will environmental conditions shift with climate change & with human activities?
Step 3	How will shifting conditions and shifting species affect SAV meadow coverage into the future?

Predicting the future in three steps

Step 1	**How have past environmental conditions affected seagrass and aquatic plant communities?**
Step 2	How will environmental conditions shift with climate change & with human activities?
Step 3	How will shifting conditions and shifting species affect SAV meadow coverage into the future?

Predicting the future in three steps

Step 1

How have past environmental conditions affected seagrass and aquatic plant communities?

VIMS aerial SAV survey data (1984-2020)

Vegetation cover

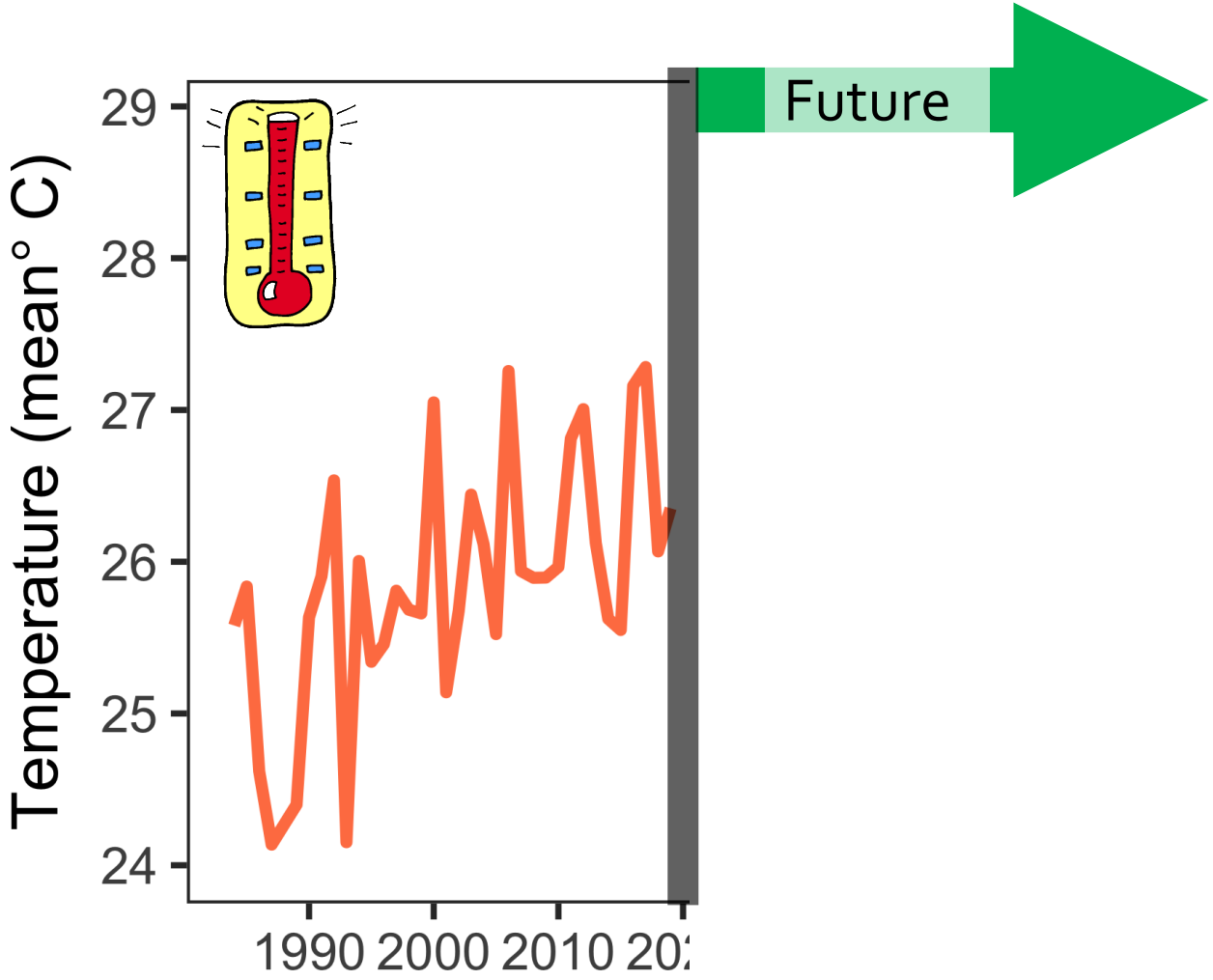
VIMS SAV Observation data (1984-2020)

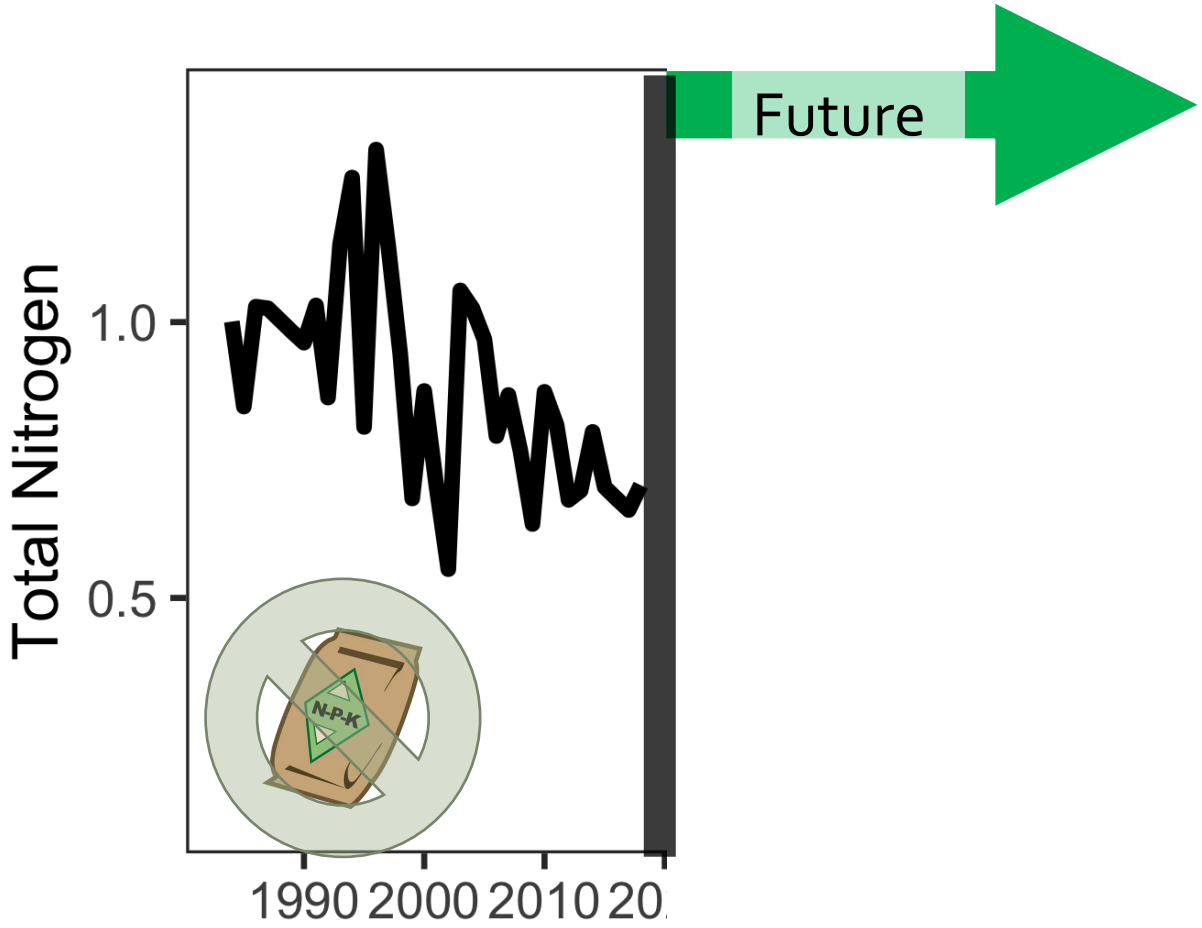
Species presence/absence

Chesapeake Bay Program water quality stations (1984-2020)

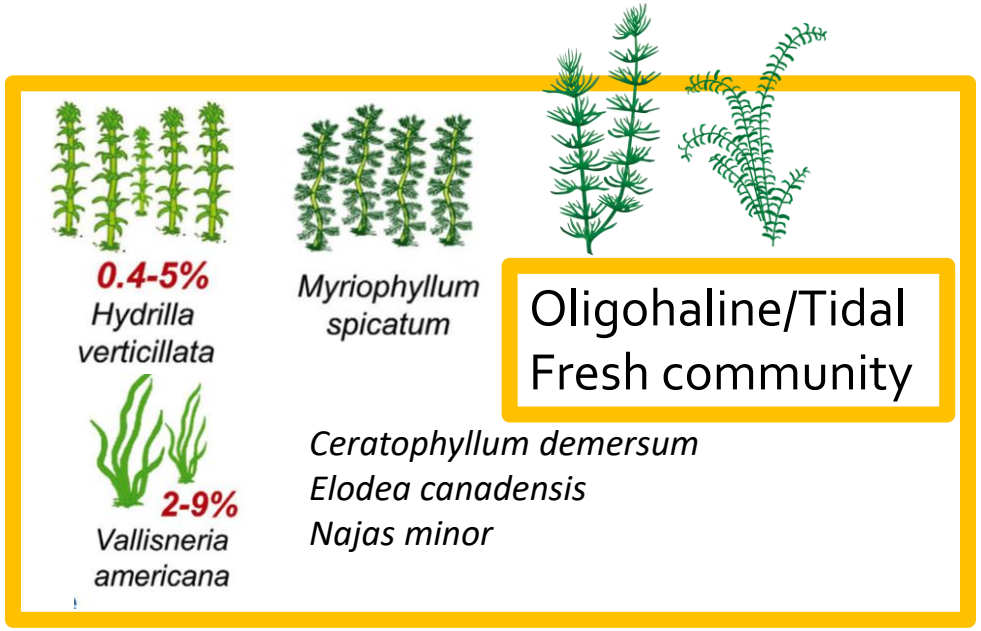
Temperature, Salinity, Nitrogen, Phosphorus, Water Clarity, Chlorophyll-a 1984-2020

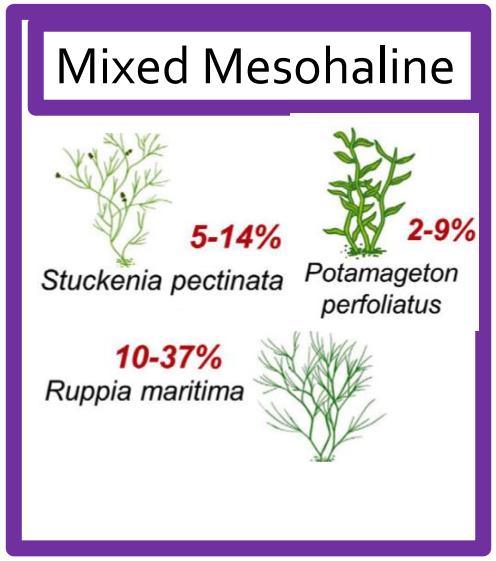
Step 1: Environmental conditions have changed from climate change and human activities

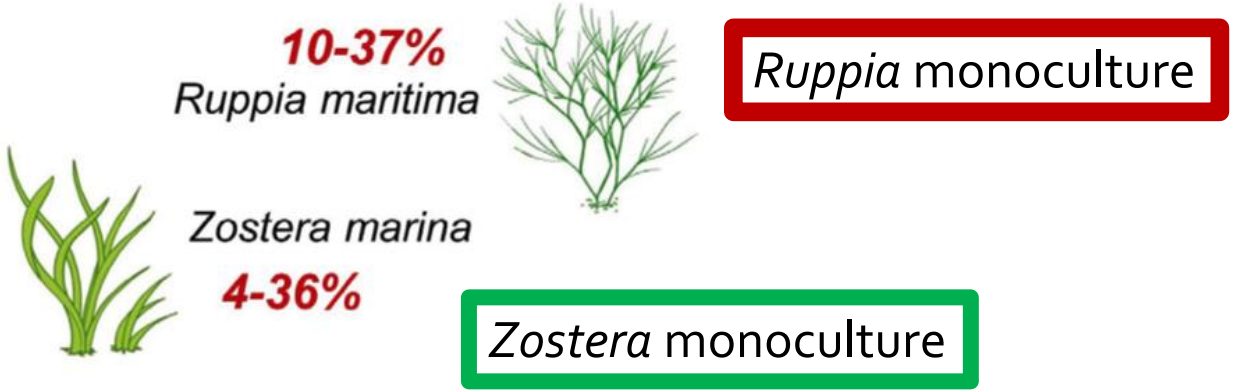


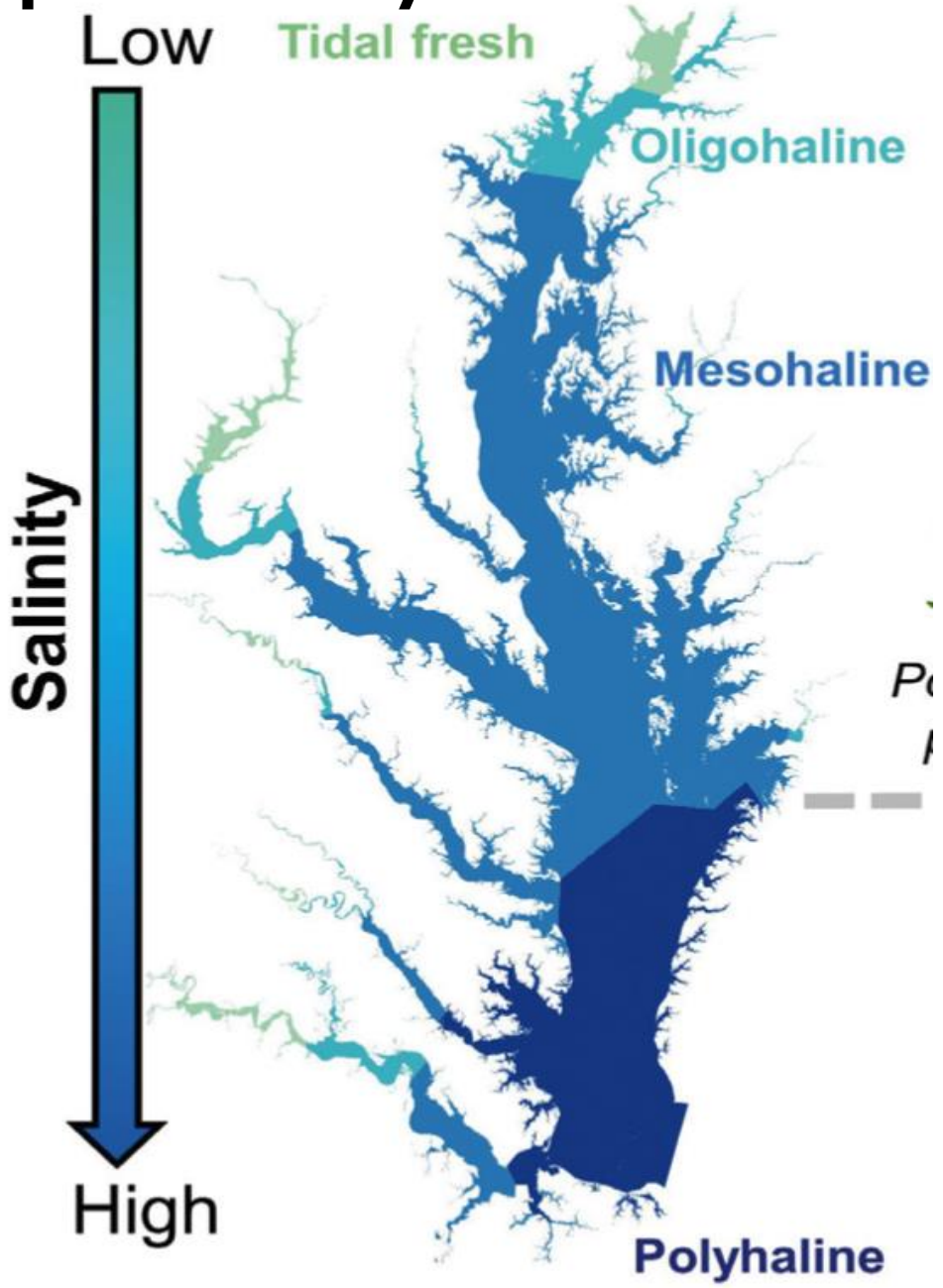


Step 1: ID major communities of Chesapeake Bay seagrass and vegetation









Step 1: ID major communities of Chesapeake Bay seagrass and vegetation

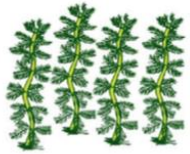
Mixed Mesohaline


5-14%
Stuckenia pectinata


2-9%
Potamageton perfoliatus


10-37%
Ruppia maritima


0.4-5%
Hydrilla verticillata


Myriophyllum spicatum

Oligohaline/Tidal Fresh community


2-9%
Vallisneria americana

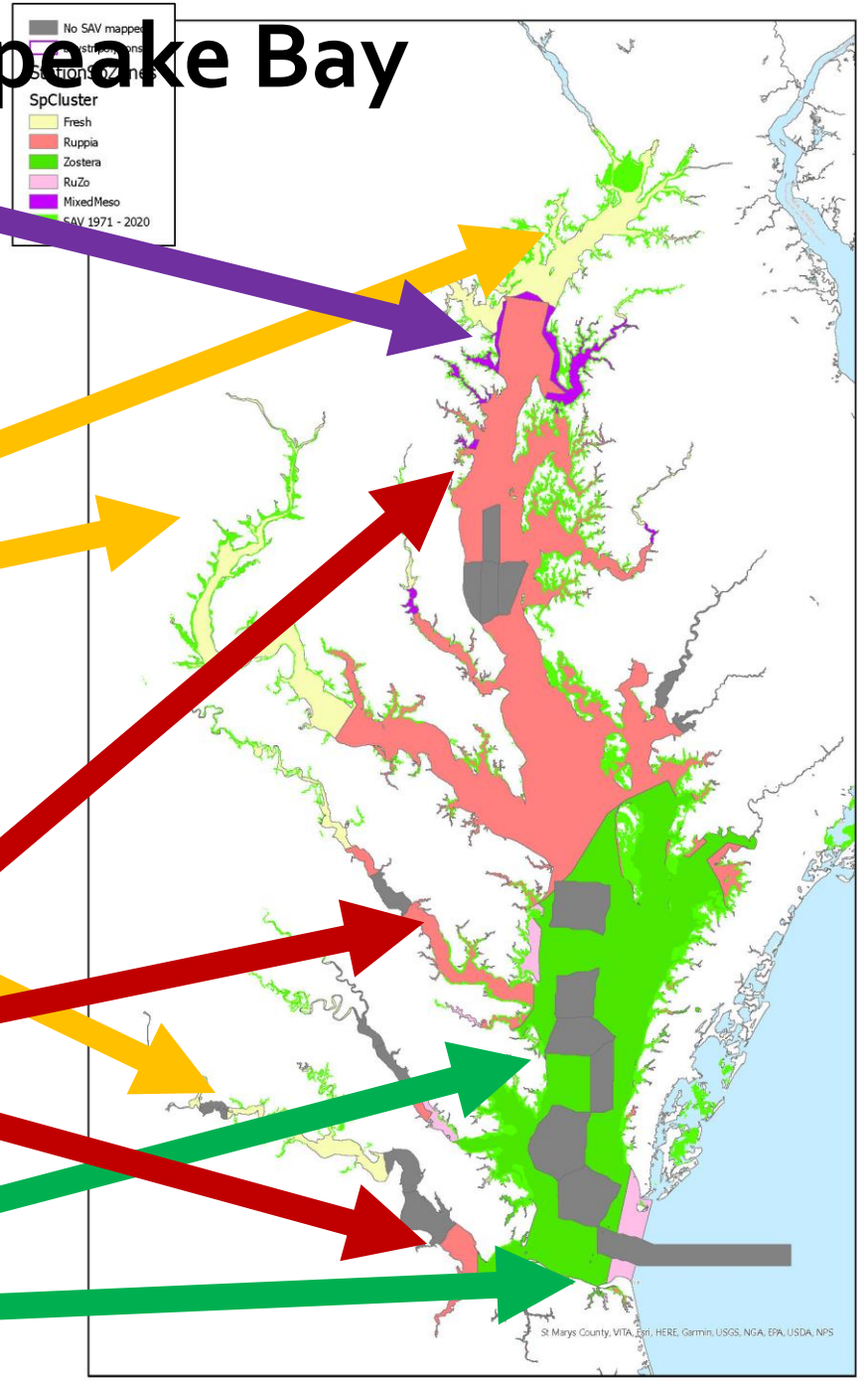
Ceratophyllum demersum
Elodea canadensis
Najas minor

10-37%
Ruppia maritima

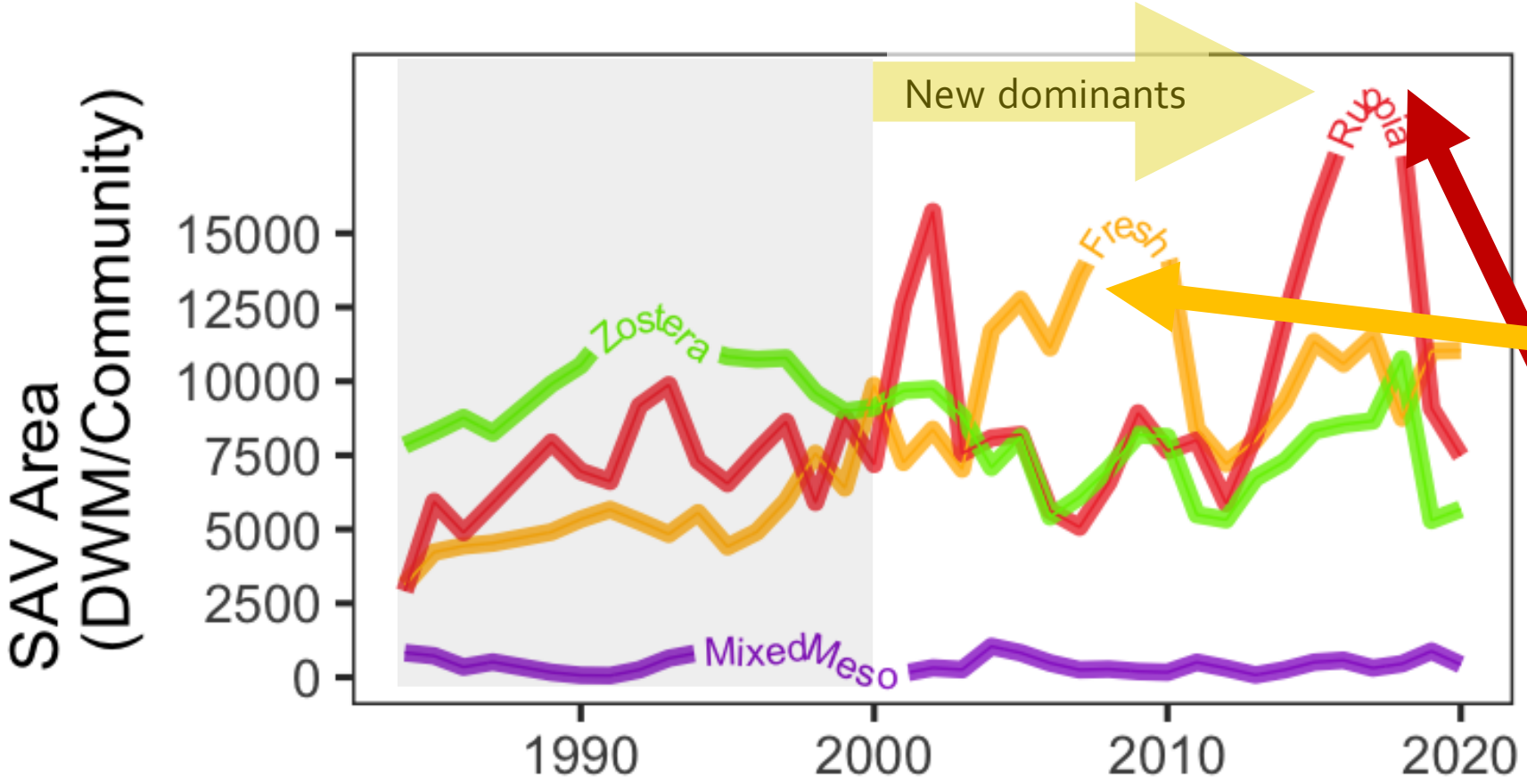
Ruppia monoculture


Zostera marina
4-36%

Zostera monoculture



Step 1: Dominant communities have changed over time in response to climate and management



Tidal fresh and widgeongrass are the dominant communities now

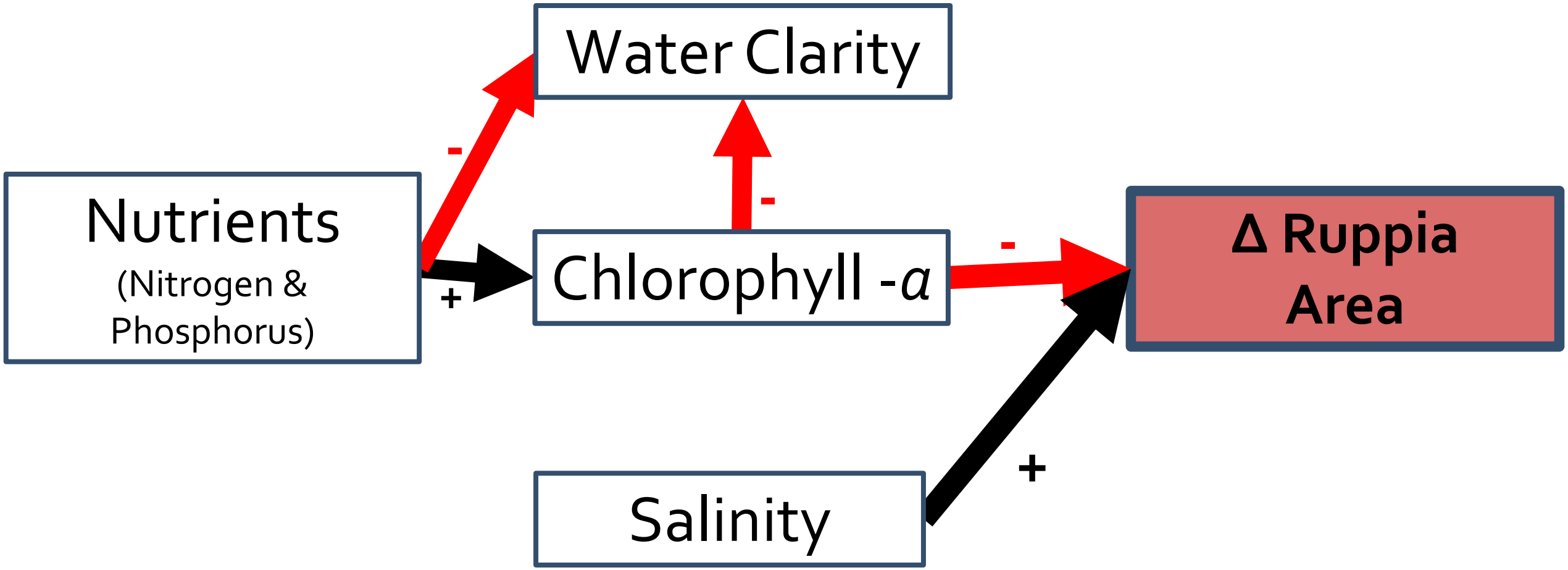
Predicting the future in three steps

Step 1	How have past environmental conditions affected seagrass and aquatic plant communities?

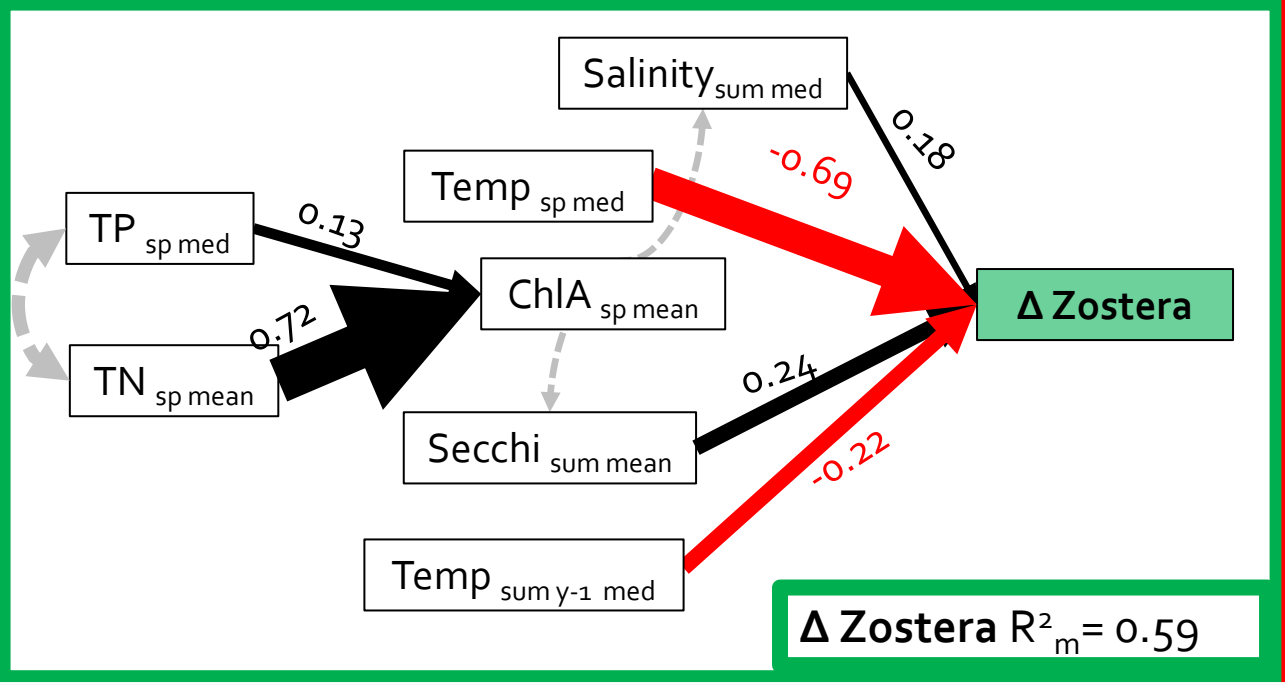
Build structural equation models to explain how past environmental changes have affected each dominant community

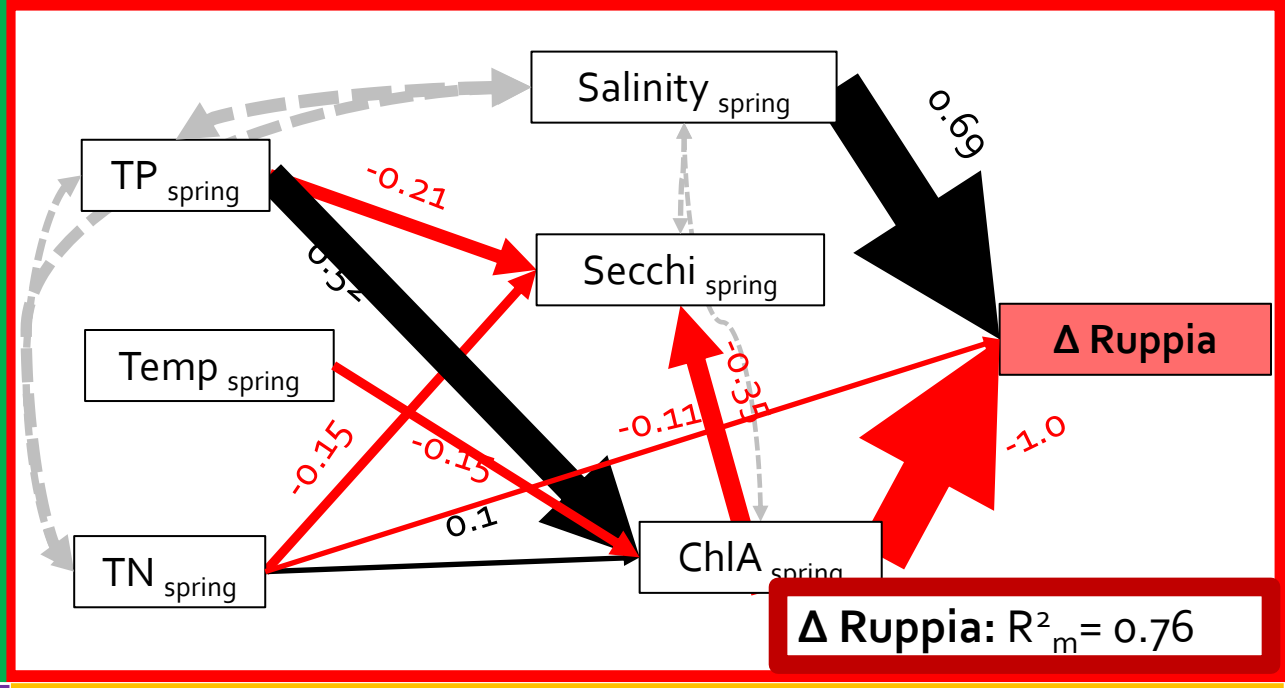
Structural Equation Modelling

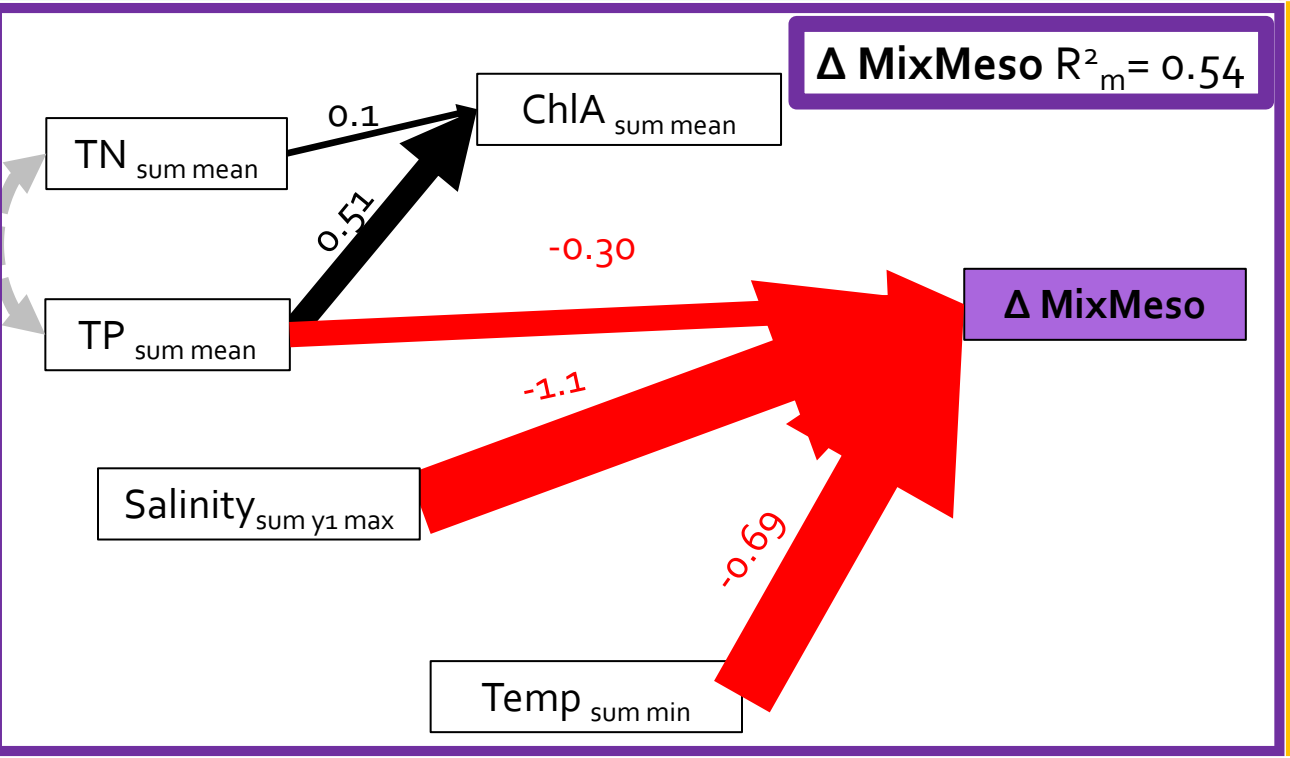
example from *Ruppia*

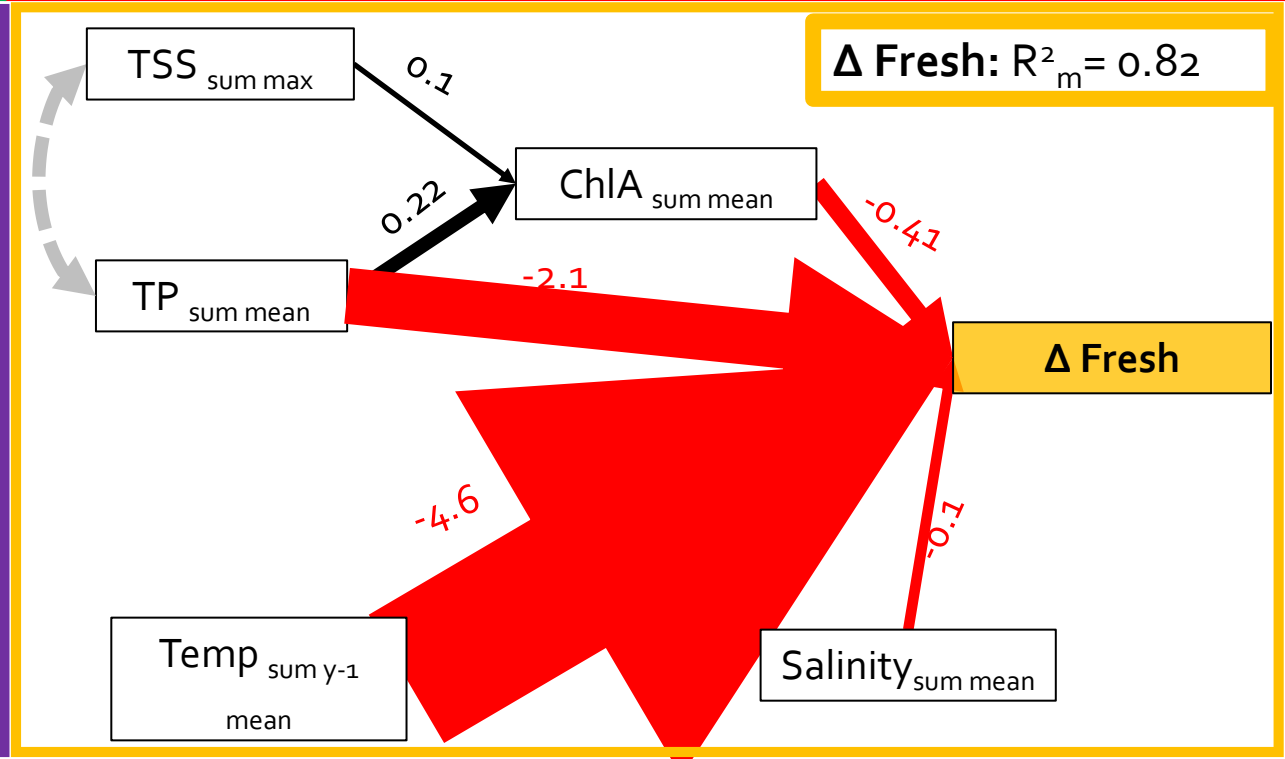


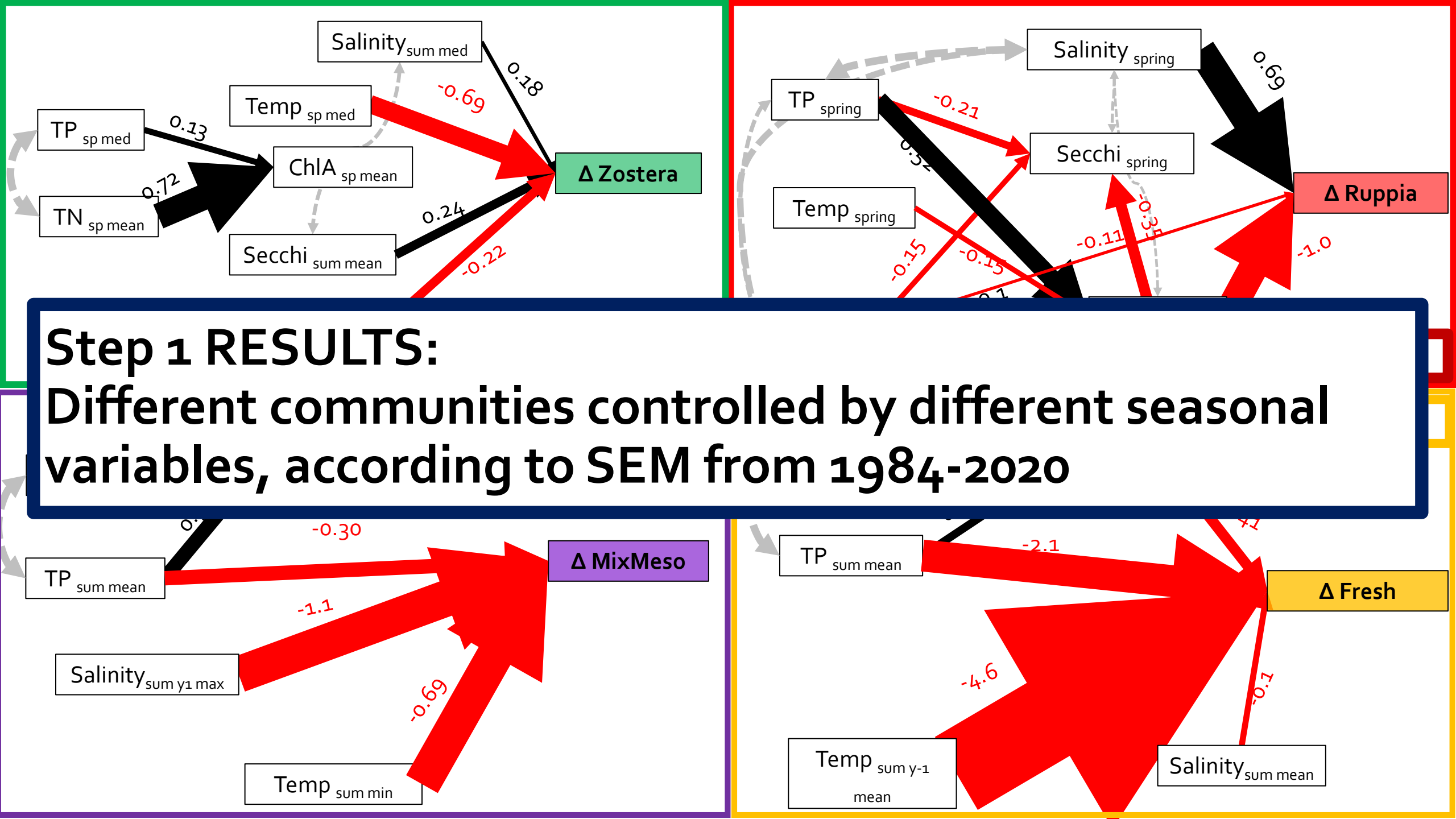
Δ Widg: $R^2_c = 0.59$


Salinity sum med
0.18
Temp sp med
-0.69
TP sp med
0.13
ChlA sp mean
Δ Zostera
0.72
TN sp mean
0.24
Secchi sum mean
-0.22
Temp sum y-1 med
Δ Zostera R²m= 0.59


Salinity spring
0.69
TP spring
-0.21
Secchi spring
Δ Ruppia
Temp spring
-0.11
-0.35
-0.15
-0.15
-1.0
0.1
TN spring
ChlA spring
Δ Ruppia: R²m= 0.76


Δ MixMeso R²m= 0.54
TN sum mean
0.1
ChlA sum mean
0.51
-0.30
TP sum mean
Δ MixMeso
-1.1
Salinity sum y1 max
-0.69
Temp sum min


Δ Fresh: R²m= 0.82
TSS sum max
0.1
ChlA sum mean
-0.41
0.22
TP sum mean
-2.1
Δ Fresh
-4.6
-0.1
Temp sum y-1 mean
Salinity sum mean



Step 1 RESULTS:
Different communities controlled by different seasonal variables, according to SEM from 1984-2020

Predicting the future in three steps

Step 1	**Climate (temperature, precipitation) and human activities (nutrients) have reshaped environmental conditions and species dominance in Chesapeake Bay**
Step 2	How will environmental conditions shift with climate change & with human activities?
Step 3	How will shifting conditions and shifting species affect SAV meadow coverage into the future?

Predicting the future in three steps

Step 1	Climate (temperature, precipitation) and human activities (nutrients) have reshaped environmental conditions and species dominance in Chesapeake Bay
Step 2	**How will environmental conditions shift with climate change & with human activities?**
Step 3	How will shifting conditions and shifting species affect SAV meadow coverage into the future?

Predicting the fu

Step 2

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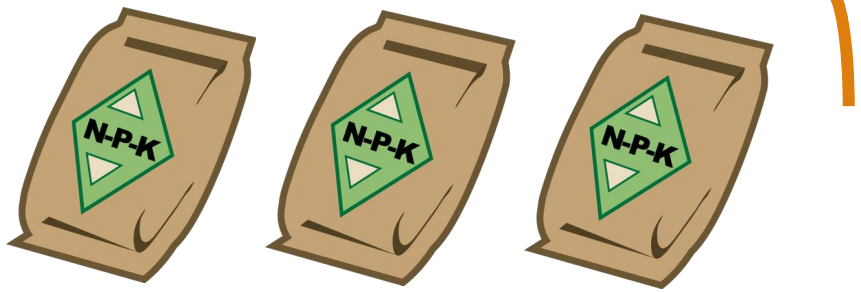
Modeling Climate Change Effects on Chesapeake Water Quality Standards and Development of 2025 Planning Targets to Address Climate Change

CBP Modeling Workgroup Report
January 2021
Chesapeake Bay Program Office, Annapolis, MD
CBP/TRS-328-21

Chesapeake Bay Program
Science, Restoration, Partnership

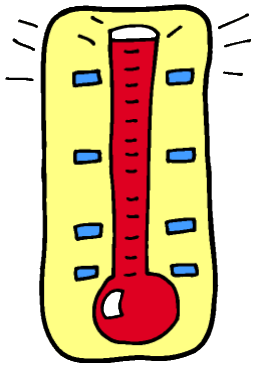
Step 2: Two future scenarios from CBP Modeling data

No Further Reductions



No further nutrient reductions

Climate change accelerates



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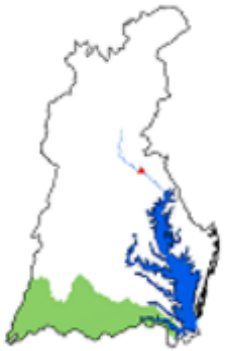
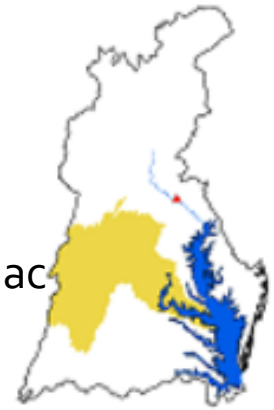
Temperature rise

Rainfall increased volume & intensity

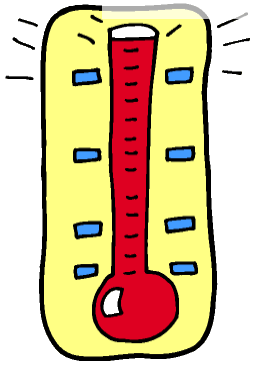




Nutrient Reductions

Agreed nutrient reductions (TMDLs)

Climate change accelerates



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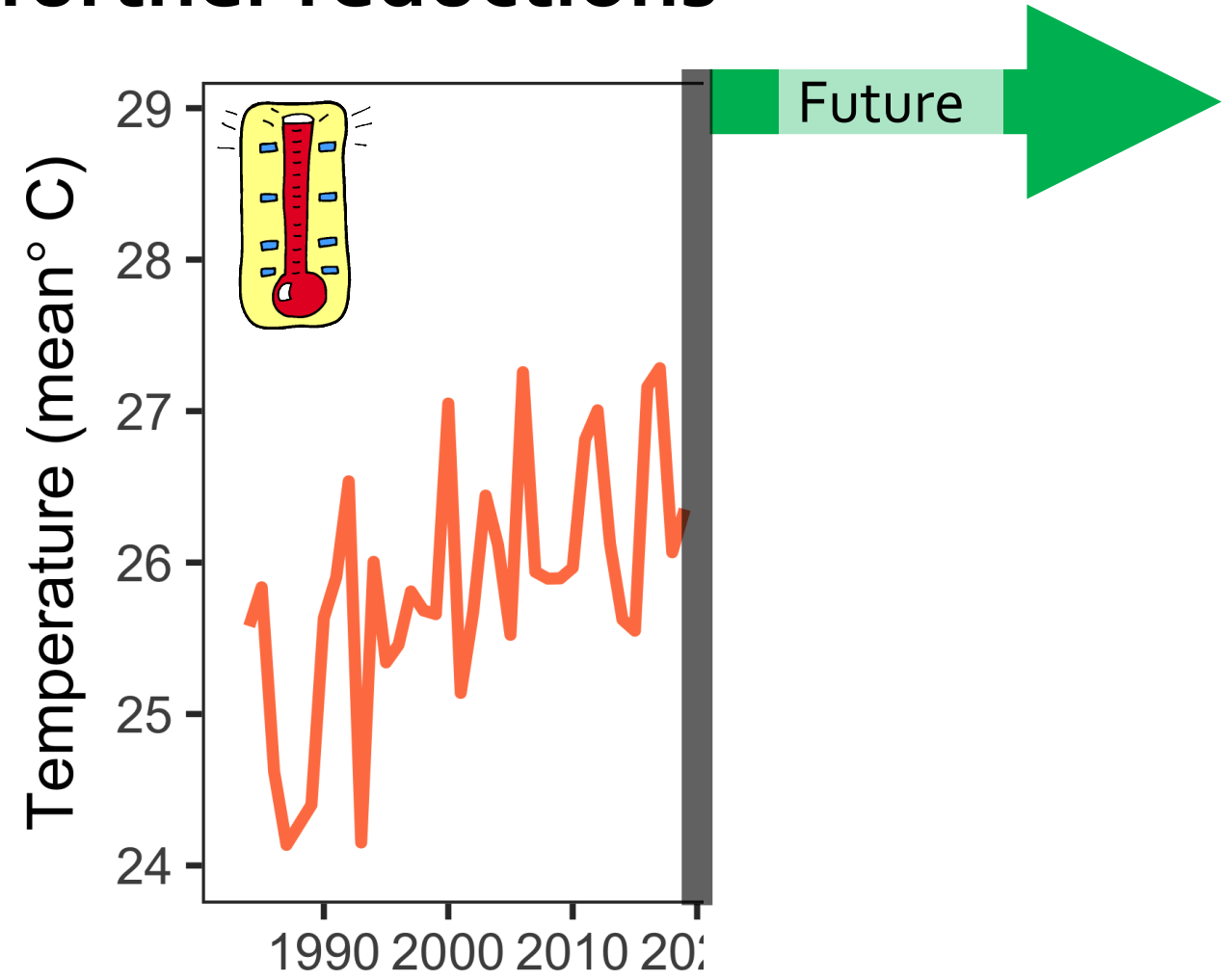
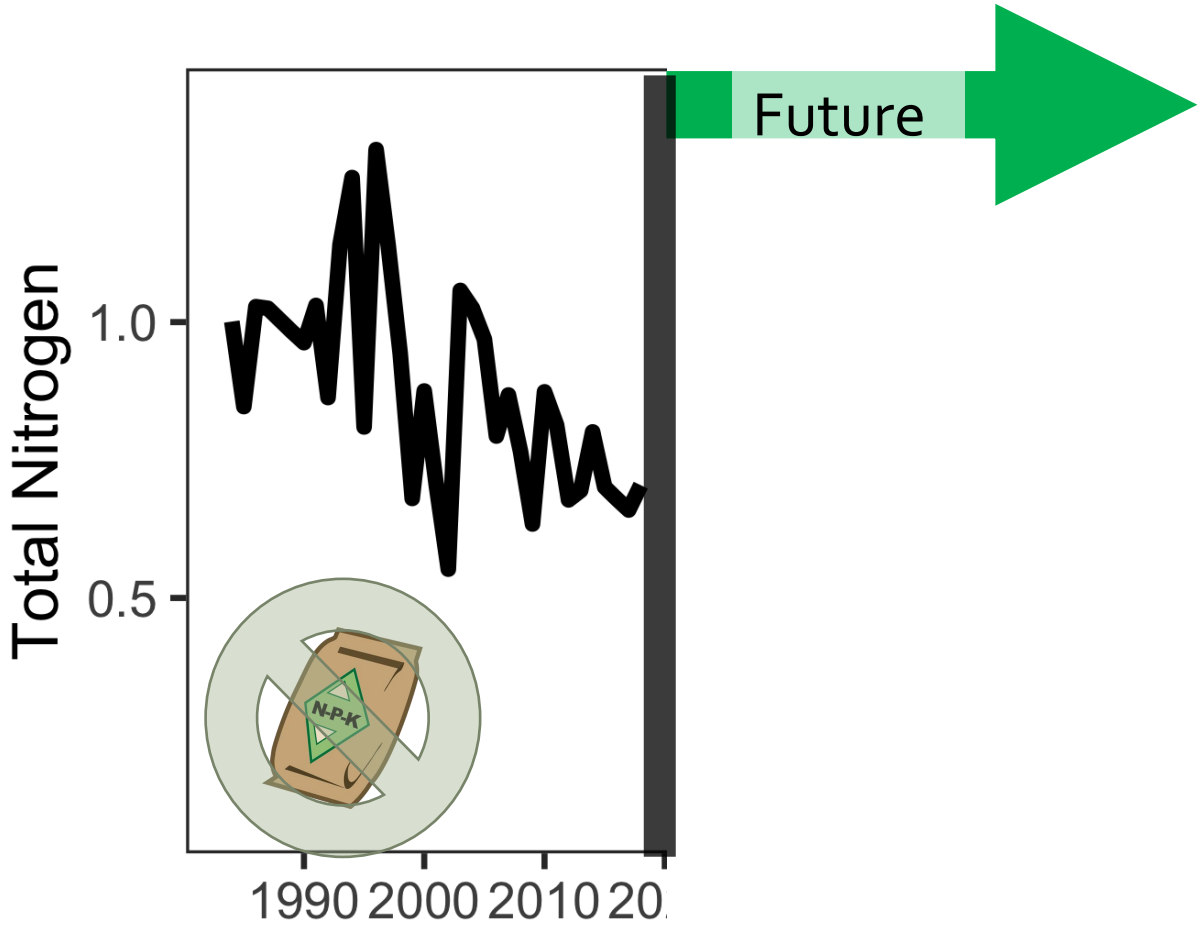
Temperature rise

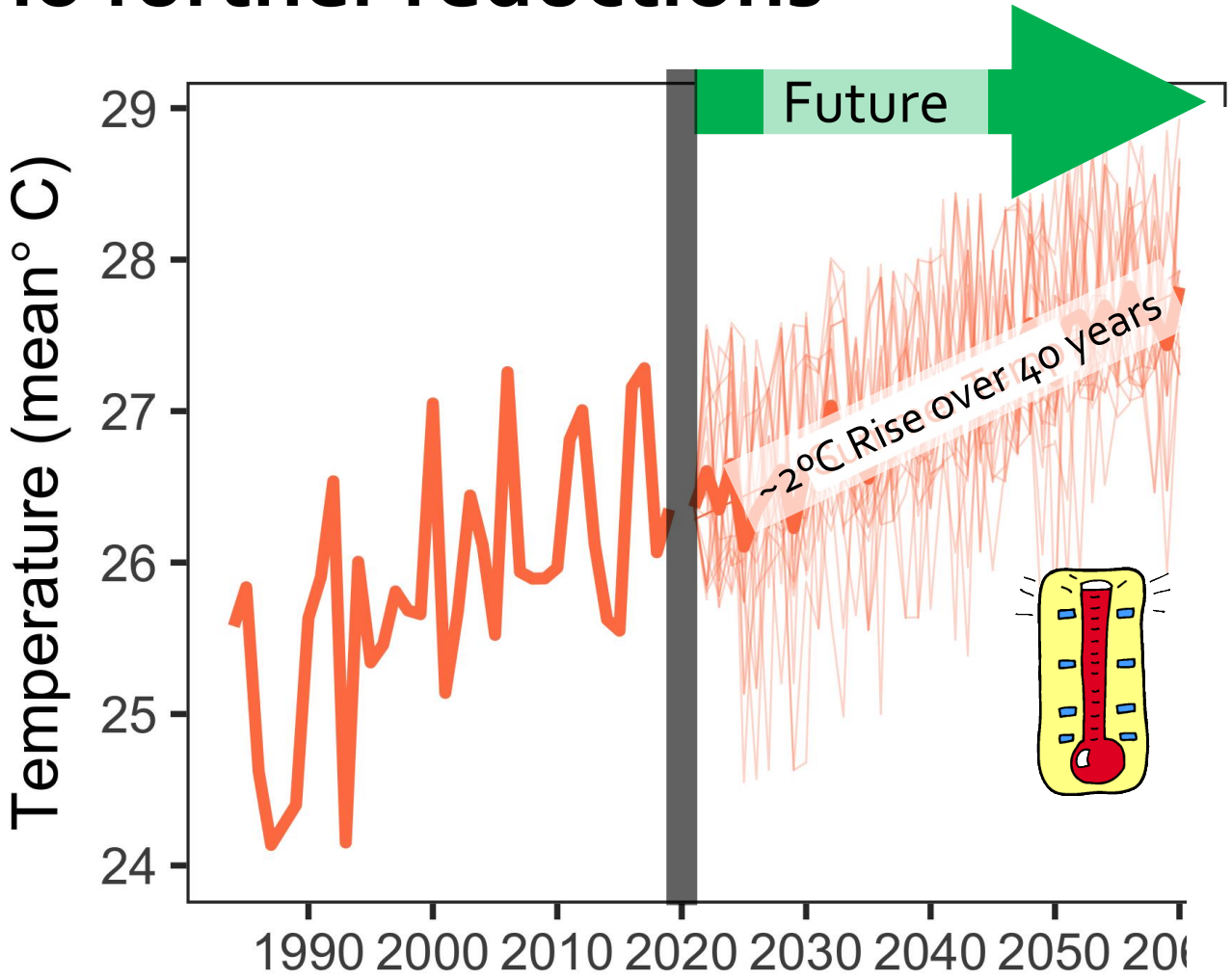
Rainfall increased volume & intensity

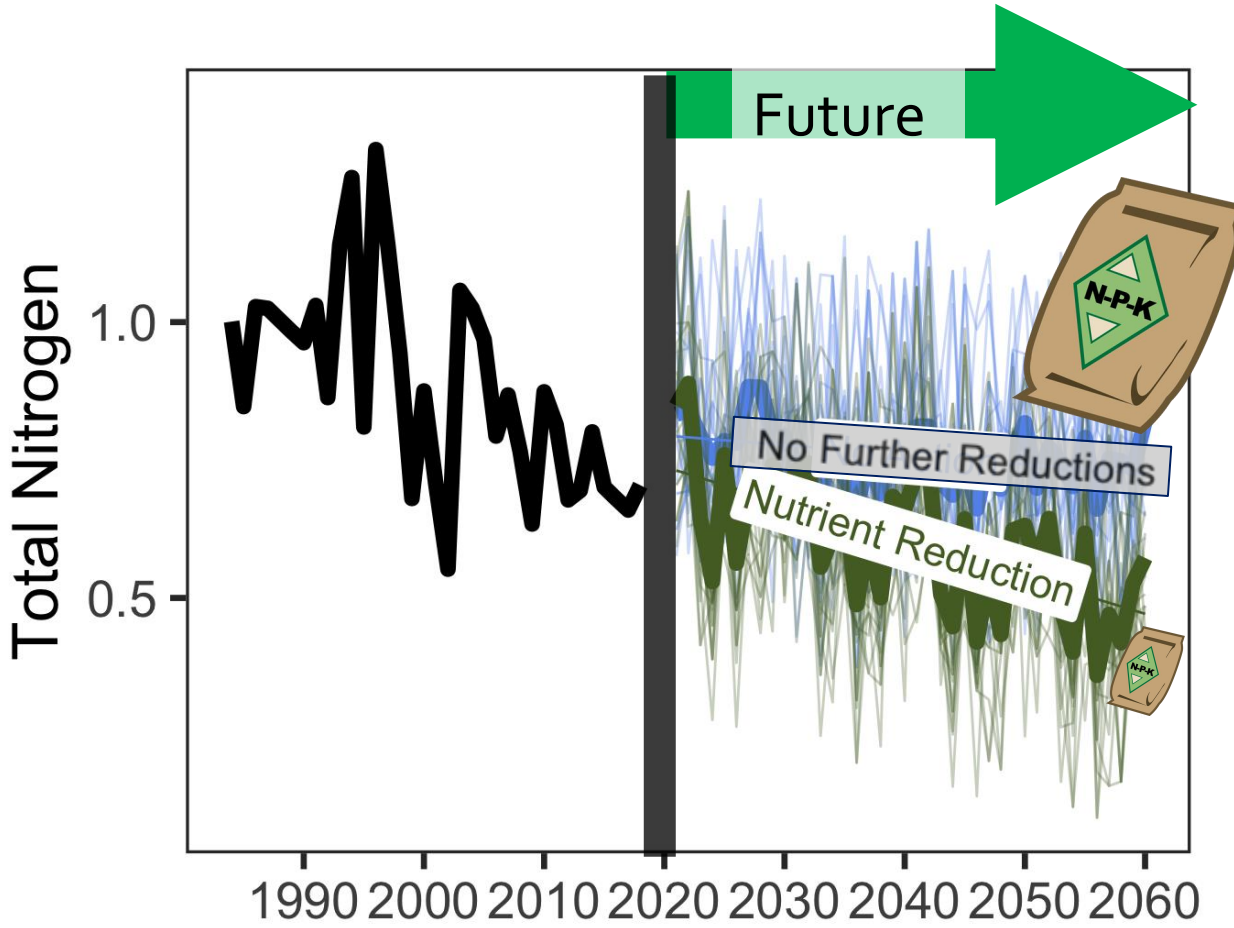
Step 2: Temperature increase & rainfall volume and frequency increase in both, nutrient reductions vs no further reductions



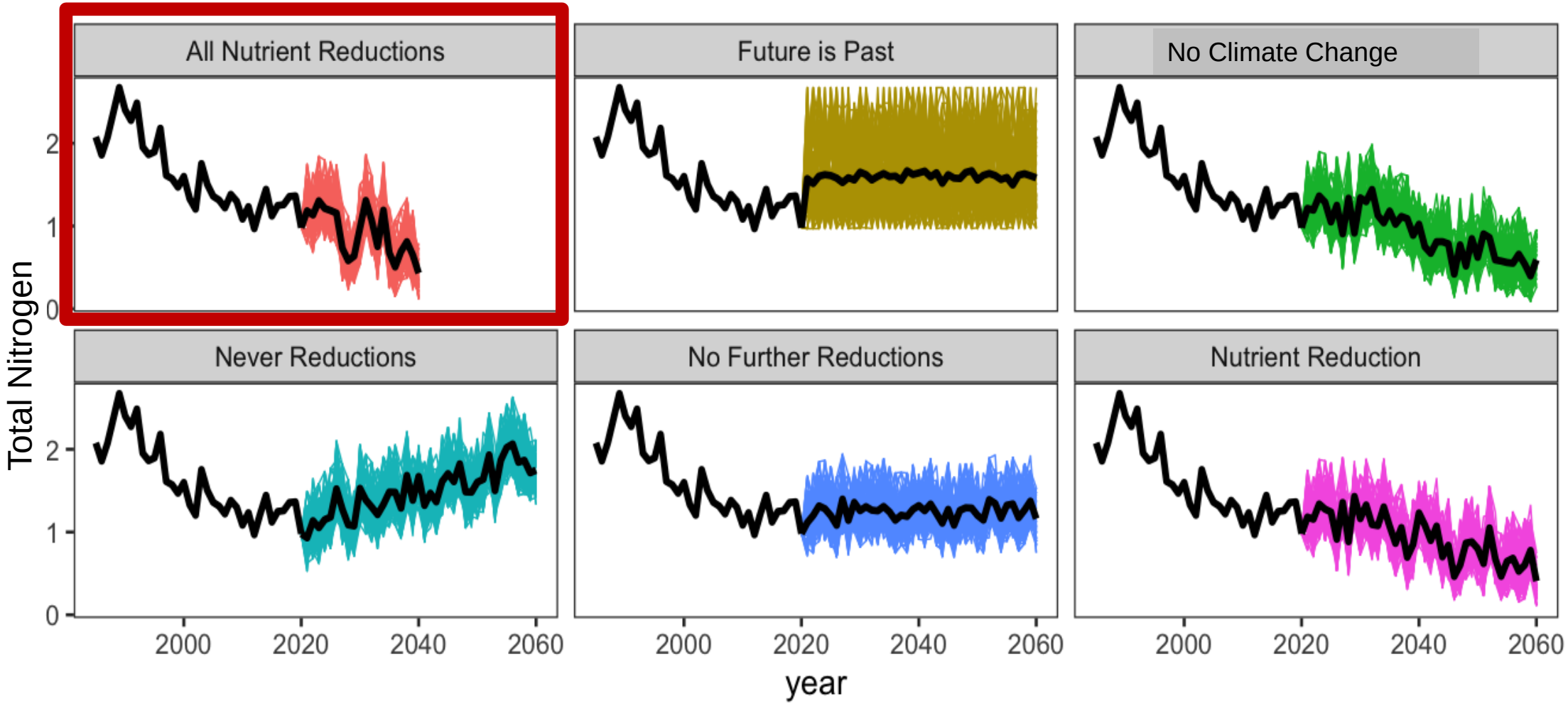


Step 2: Temperature increase & rainfall volume and frequency increase in both, nutrient reductions vs no further reductions



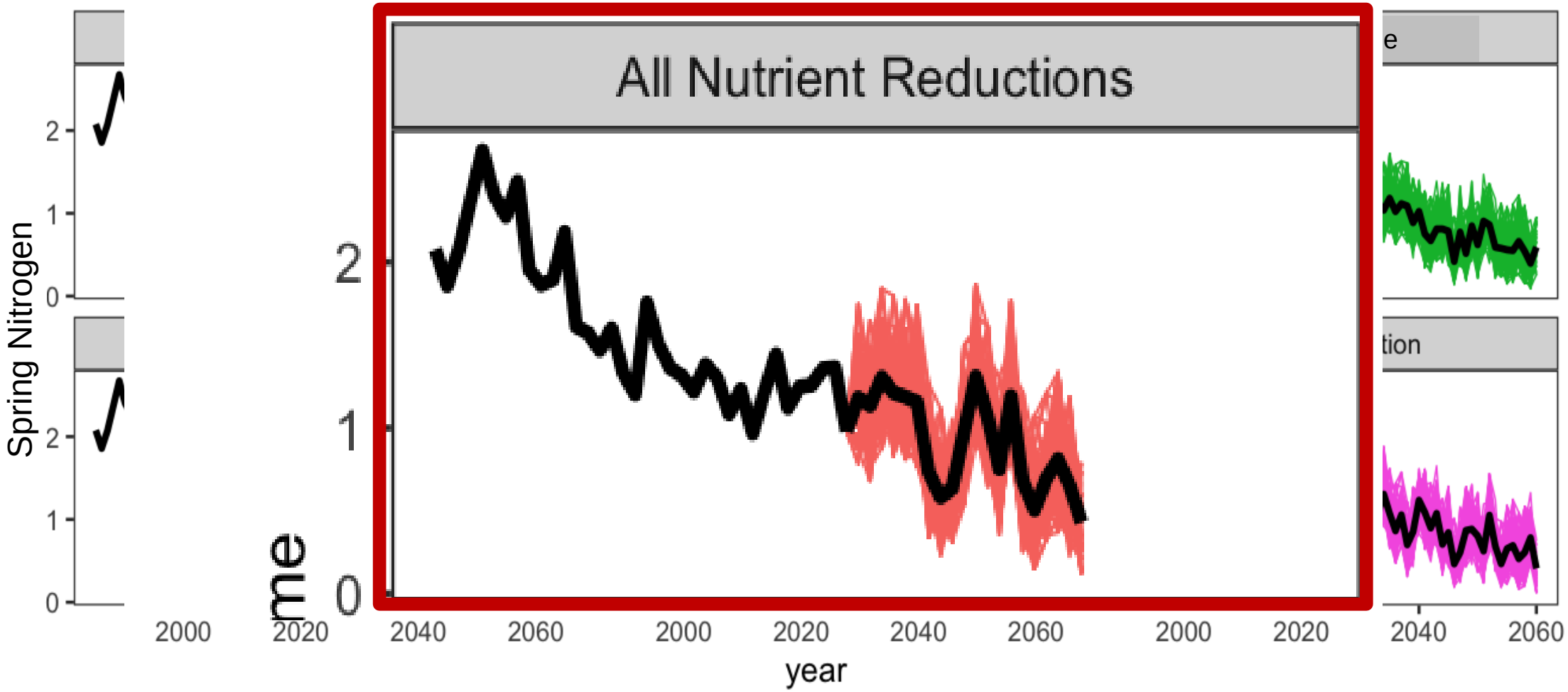


Step 2: More Scenarios! Spring Nitrogen in Freshwater zone w/ even more nutrient reductions



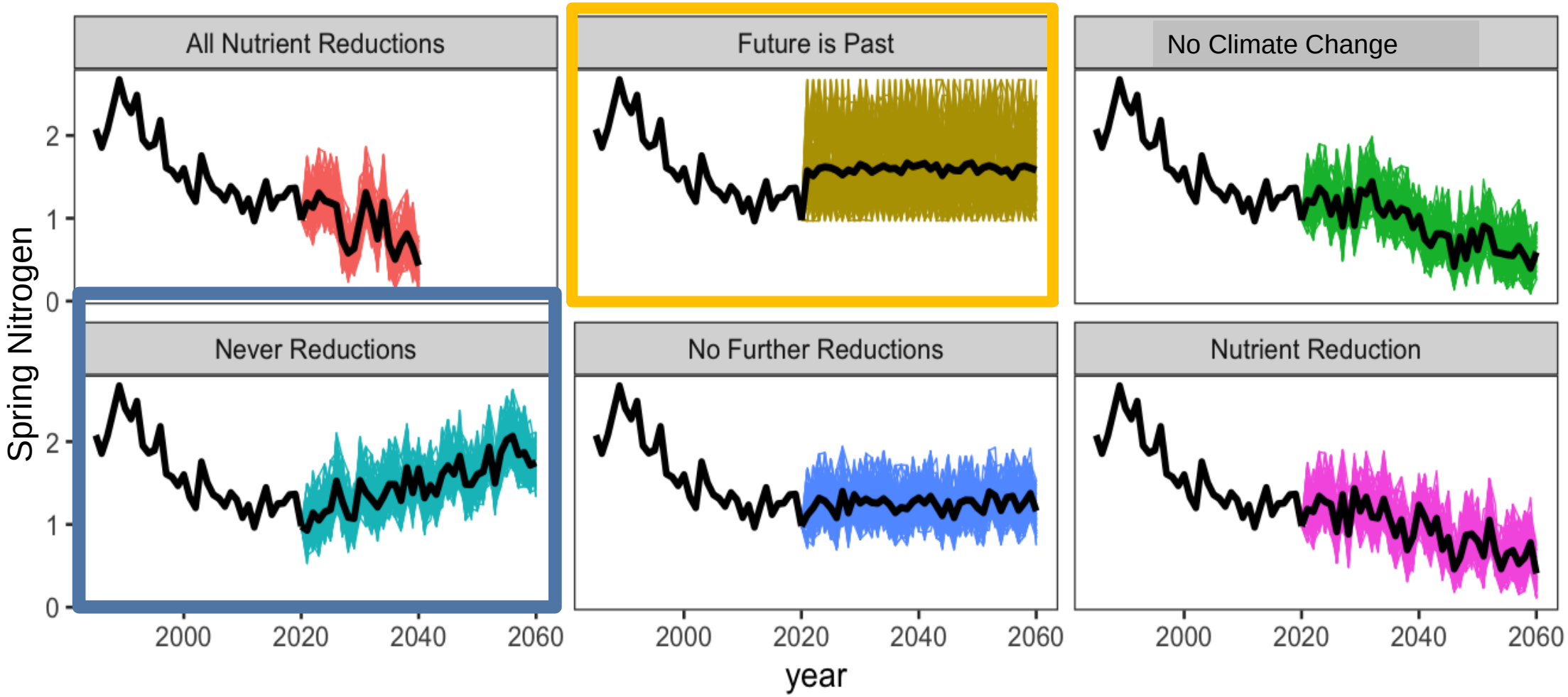
Step 2: "All Agreed Upon Nutrient Reductions"

Connowingo Dam infill + 10 million lbs of nitrogen and 1 mil lb of phosporus reduced

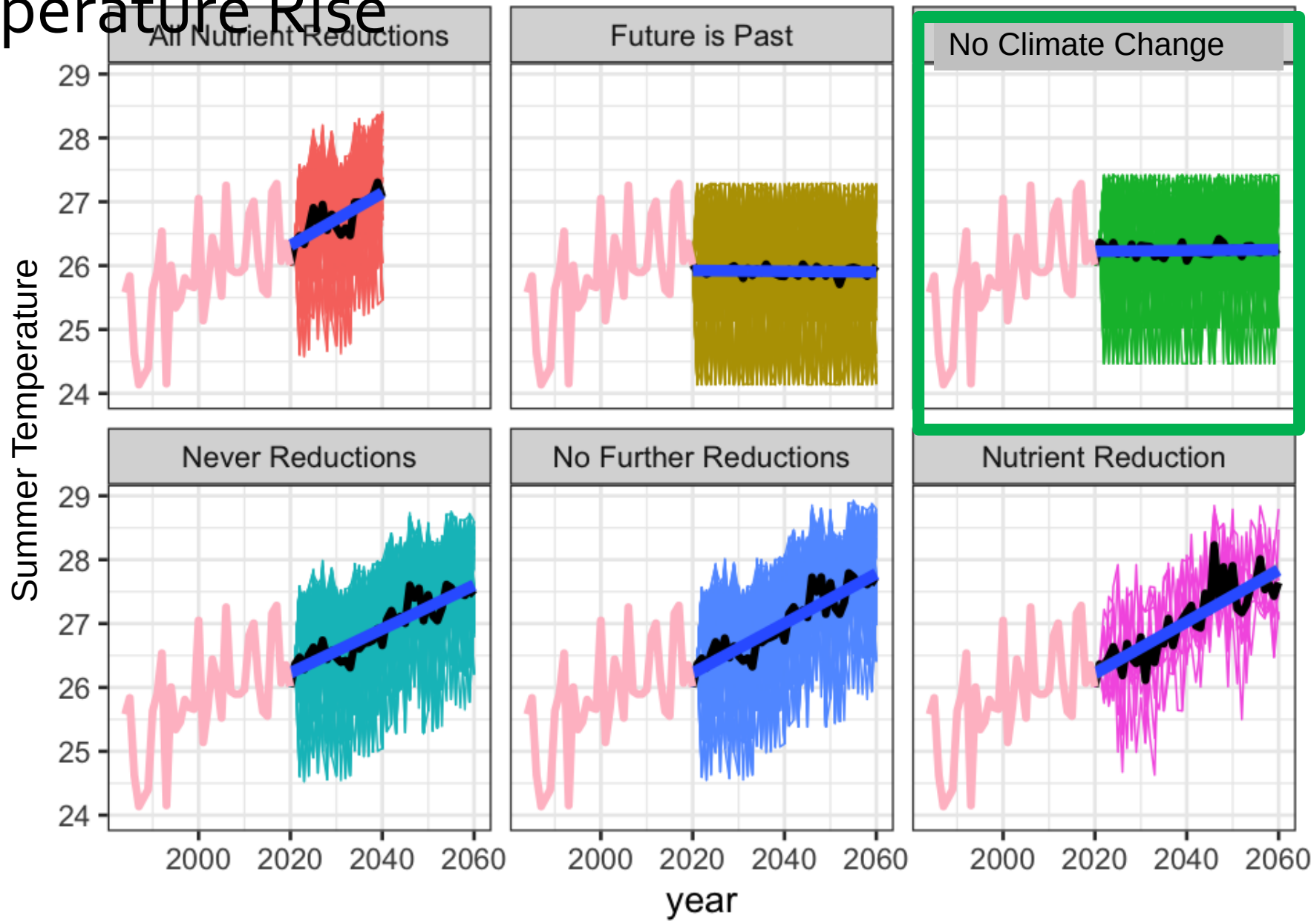


Step 2: "Control" Scenarios

To aid in comparisons



Step 2: "Control" Scenarios No Climate Change / No Temperature Rise



Predicting the future in three steps

Step 1	Climate (temperature, precipitation) and human activities (nutrients) have reshaped species dominance in CB
Step 2	**Temperature rise, precipitation volume & intensity increases are inevitable. Nutrient reductions will dictate future Bay conditions**
Step 3	How will shifting conditions and shifting species affect SAV meadow coverage into the future?

Predicting the future in three steps

Step 1	Climate (temperature, precipitation) and human activities (nutrients) have reshaped species dominance in CB
Step 2	Temperature rise, precipitation volume & intensity increases are inevitable. Nutrient reductions will dictate future Bay conditions
Step 3	**How will shifting conditions and shifting species affect SAV meadow coverage into the future?**

Predicting the future in three steps

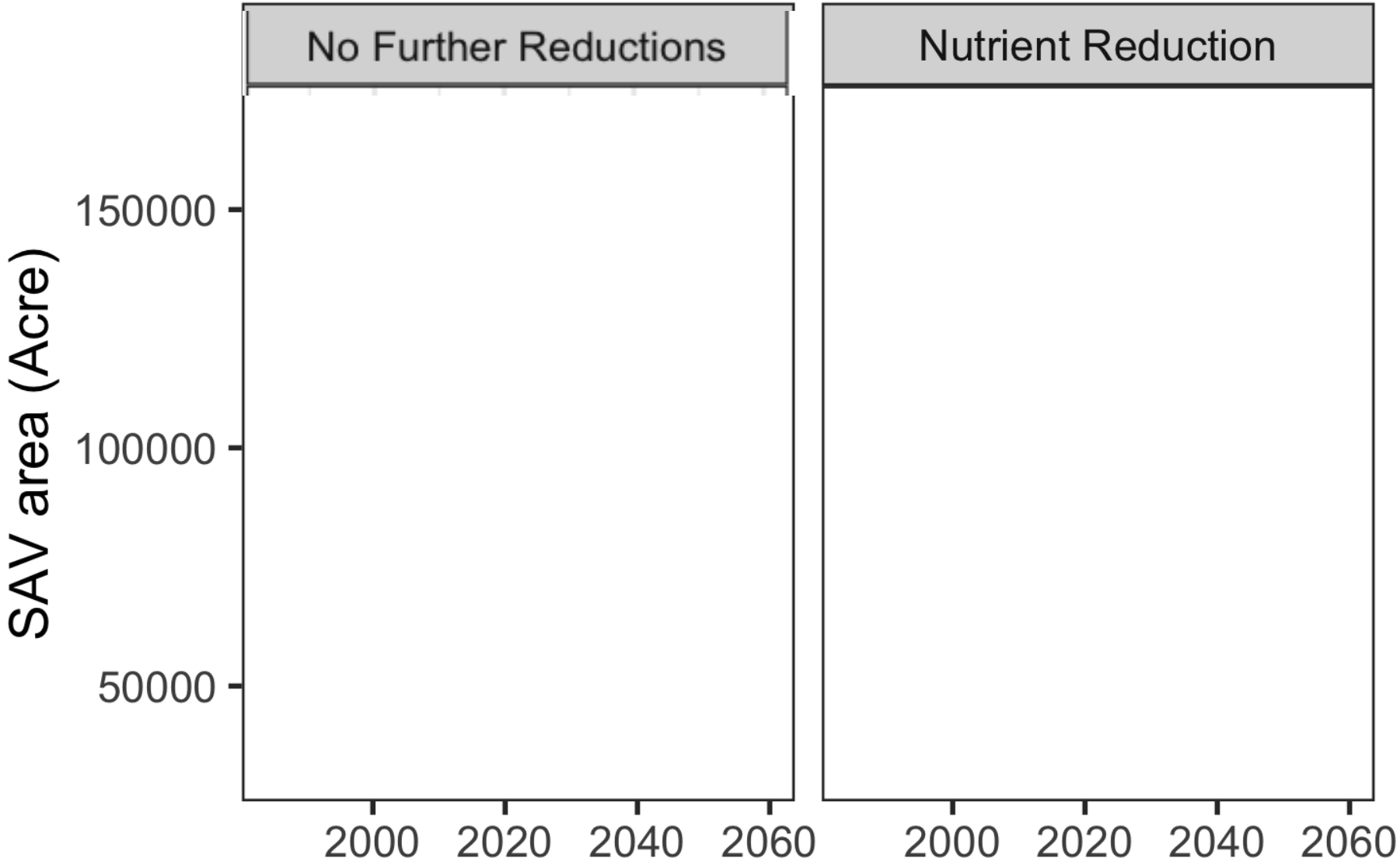
Step 3

How will shifting conditions and shifting species affect SAV meadow coverage into the future?

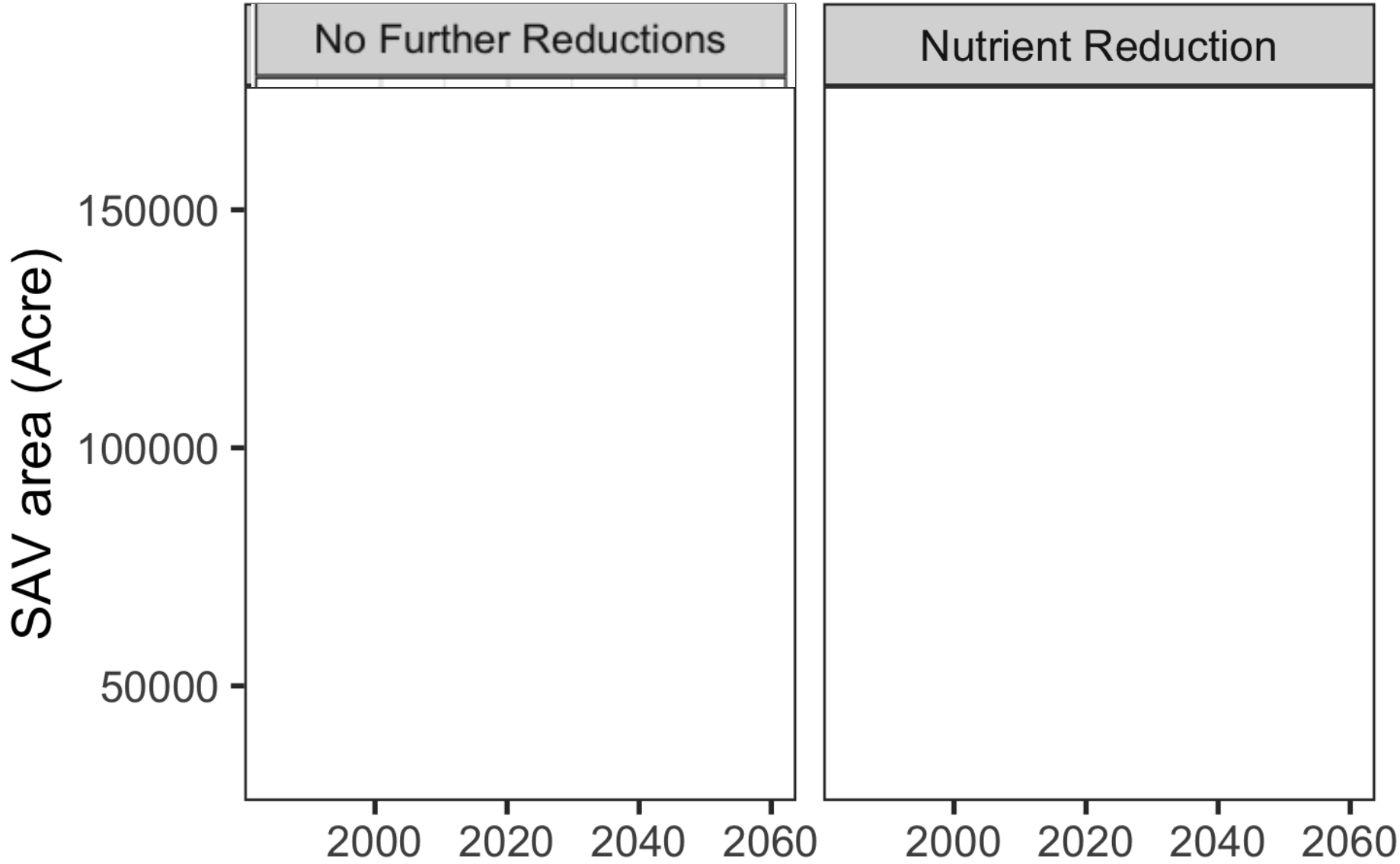
Predictive mixed effects models under two future scenarios (2021-2060)

1000 simulations for each community

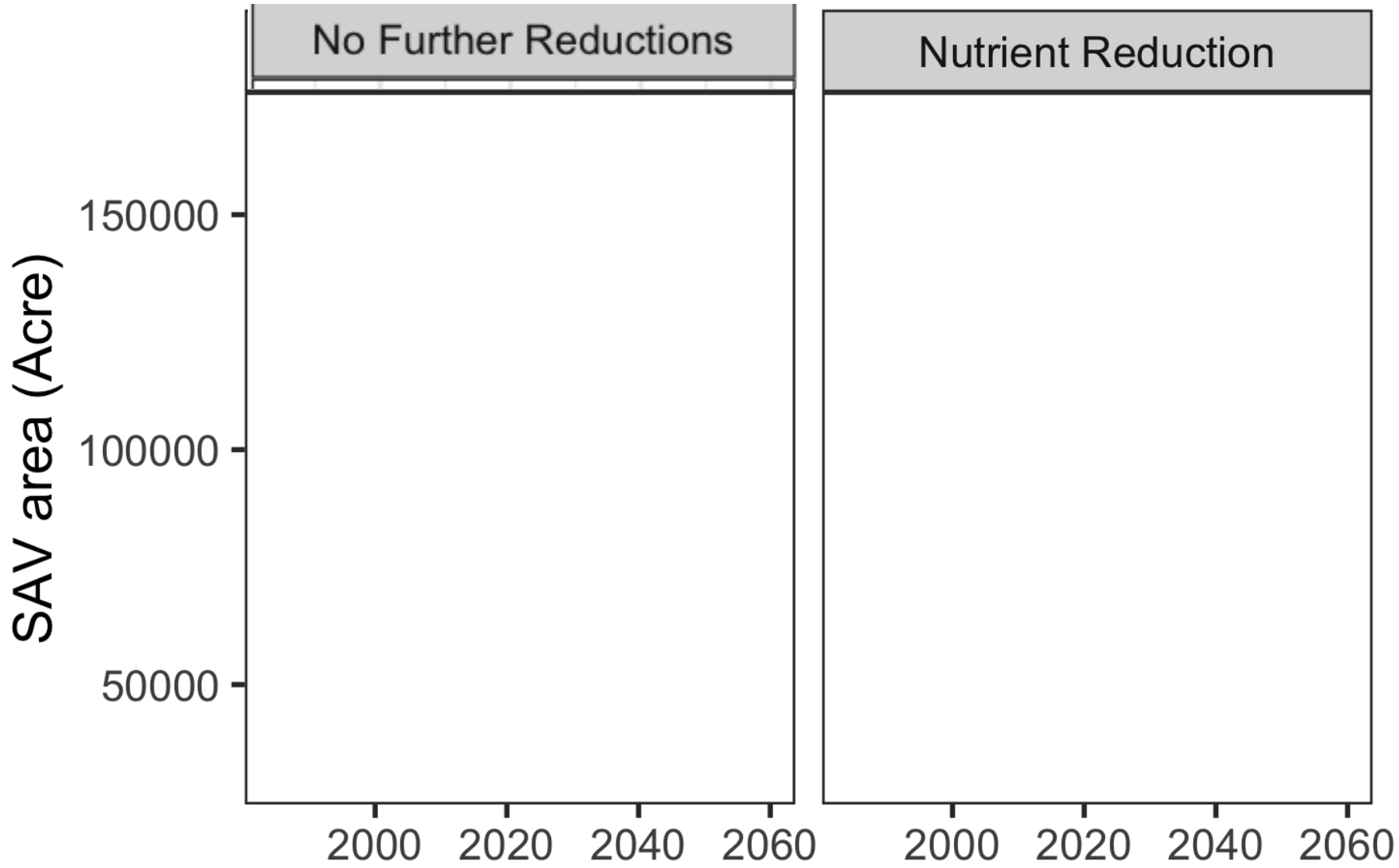
Step 3: Baywide climate change predictions|
Into the SAV Multiverse!!



Step 3: Baywide Climate change predictions|
Into the SAV Multiverse!!

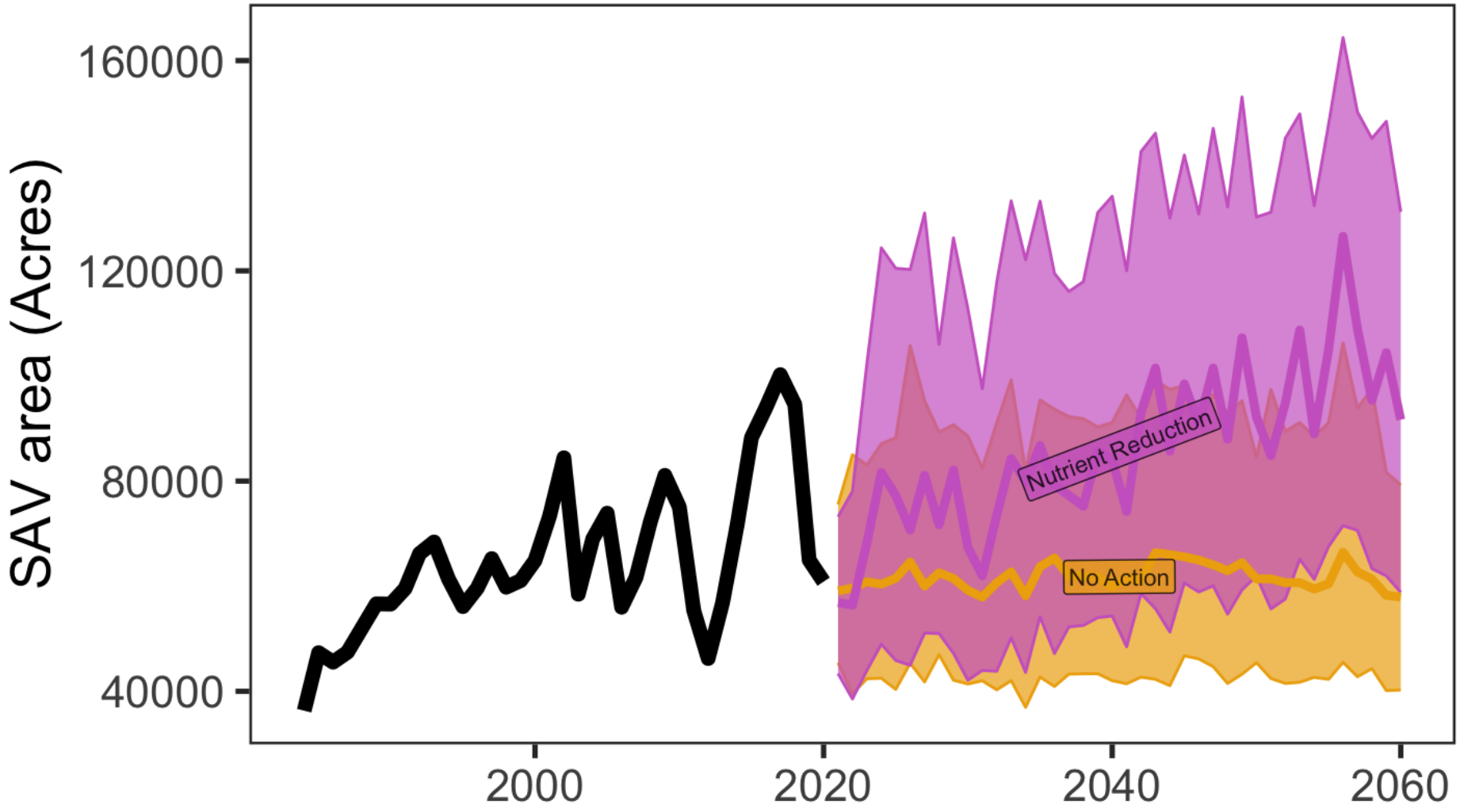


Step 3: Baywide Climate change predictions|
Into the SAV Multiverse!!



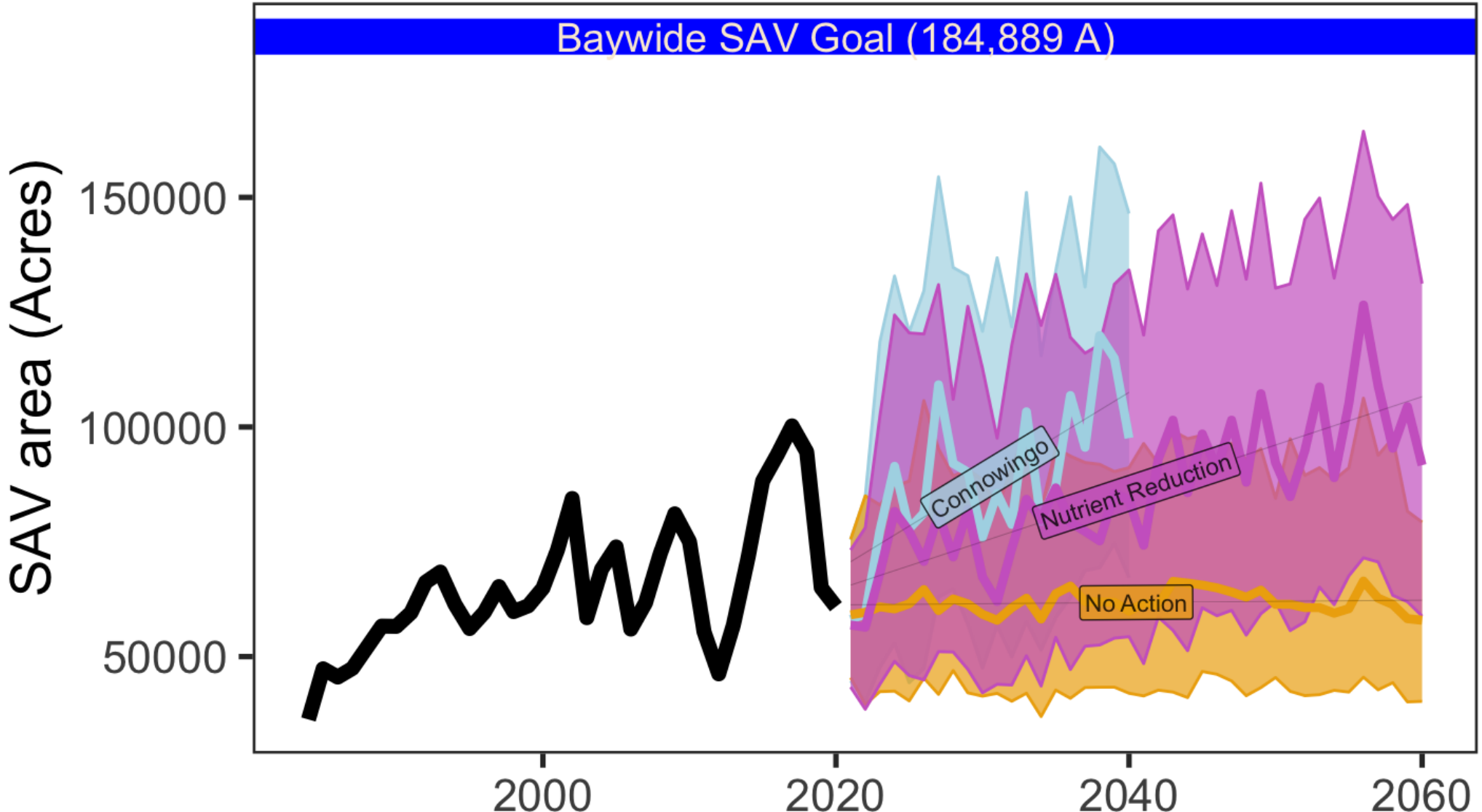
Step 3: Baywide climate change predictions|

95% simulation envelopes show +50,000 acres by 2040 if nutrient reductions continue

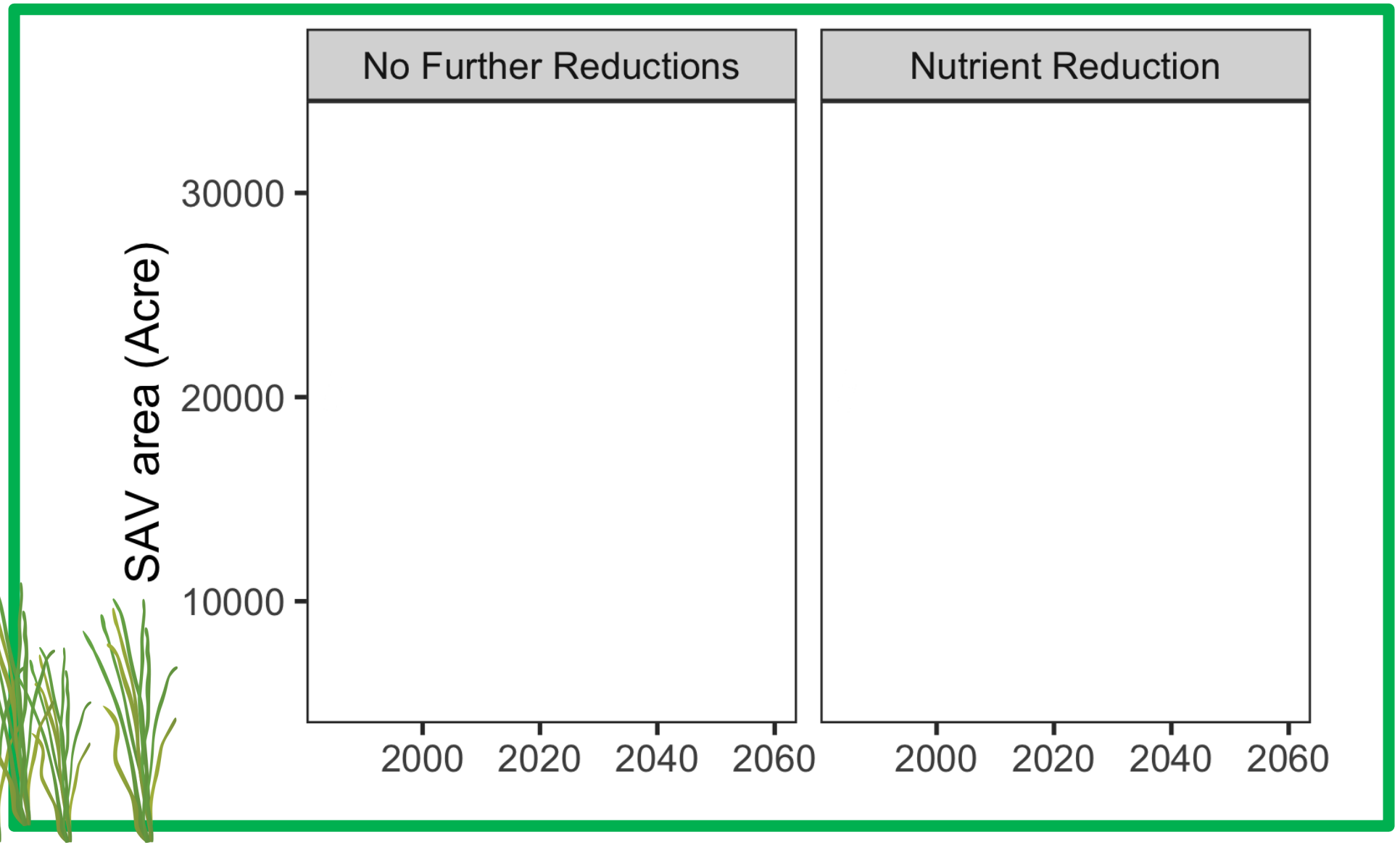


Step 3: Baywide Climate change predictions|

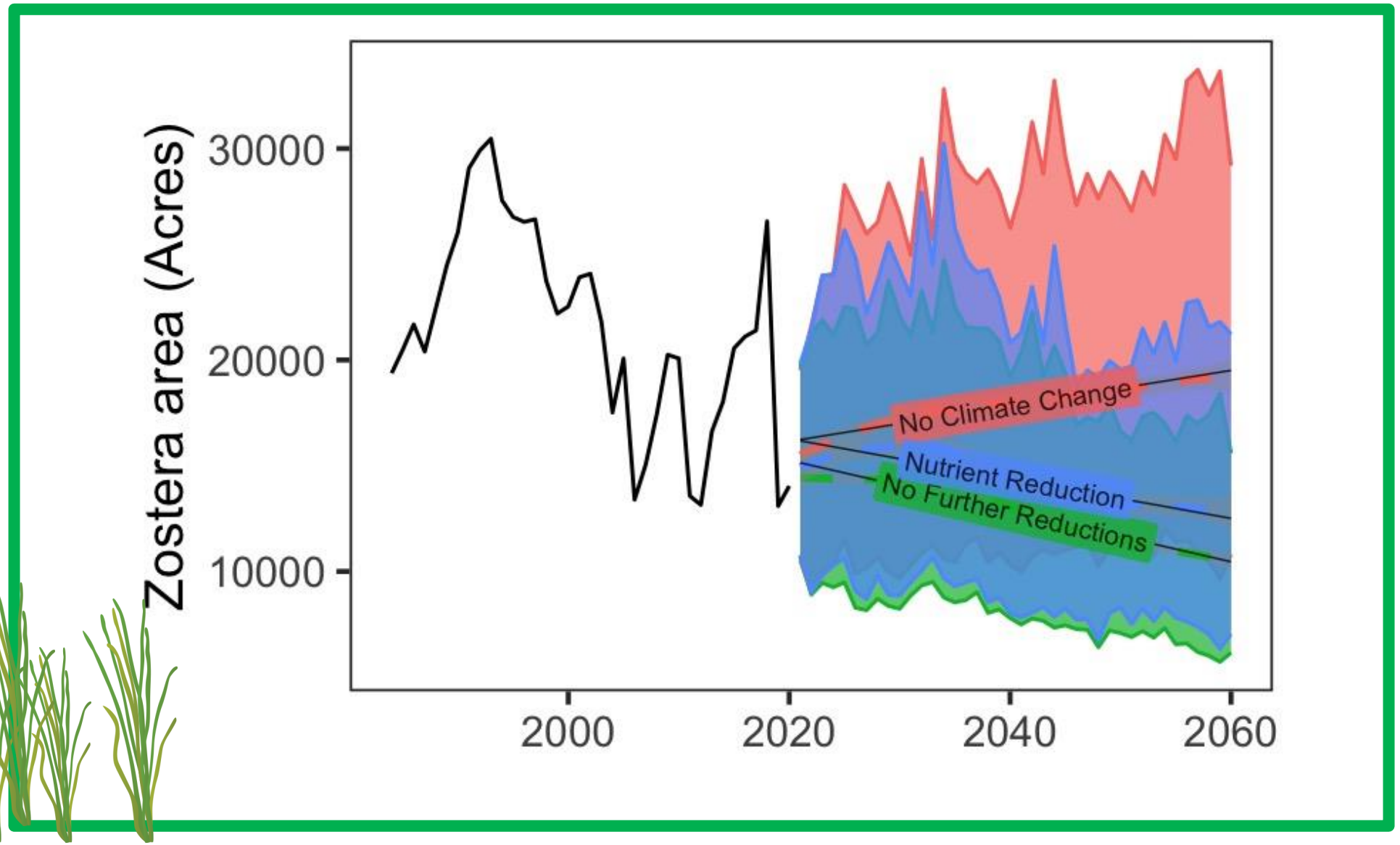
0% of simulations reach Baywide goals..but nutrient reductions get much closer by 2060!



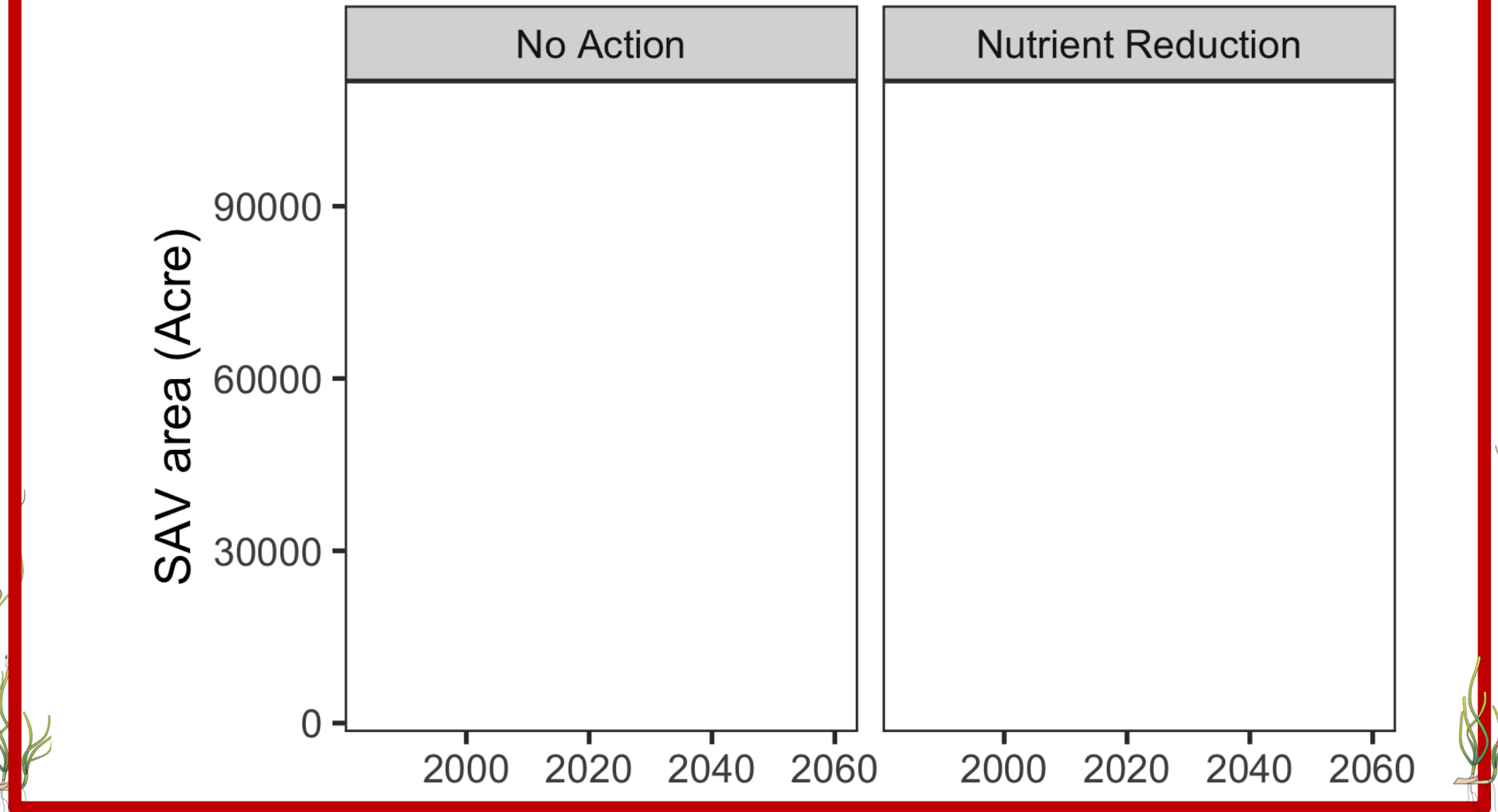
Step 3: SAV Community Climate change predictions| *Zostera* declines inevitable w Temp rise, Nutrients temper



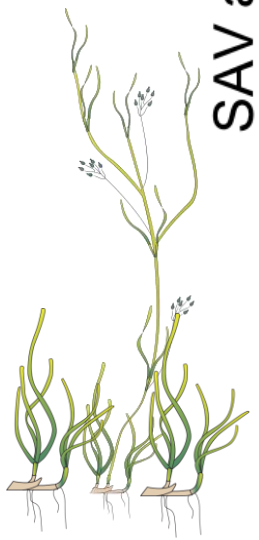
Step 3: SAV Community Climate change predictions| *Zostera* declines inevitable w Temp rise, Nutrients temper

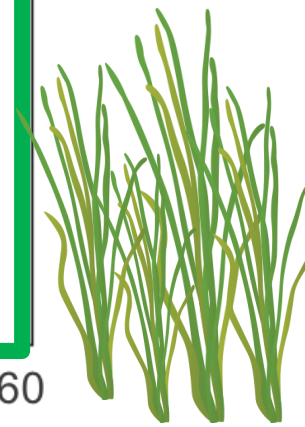


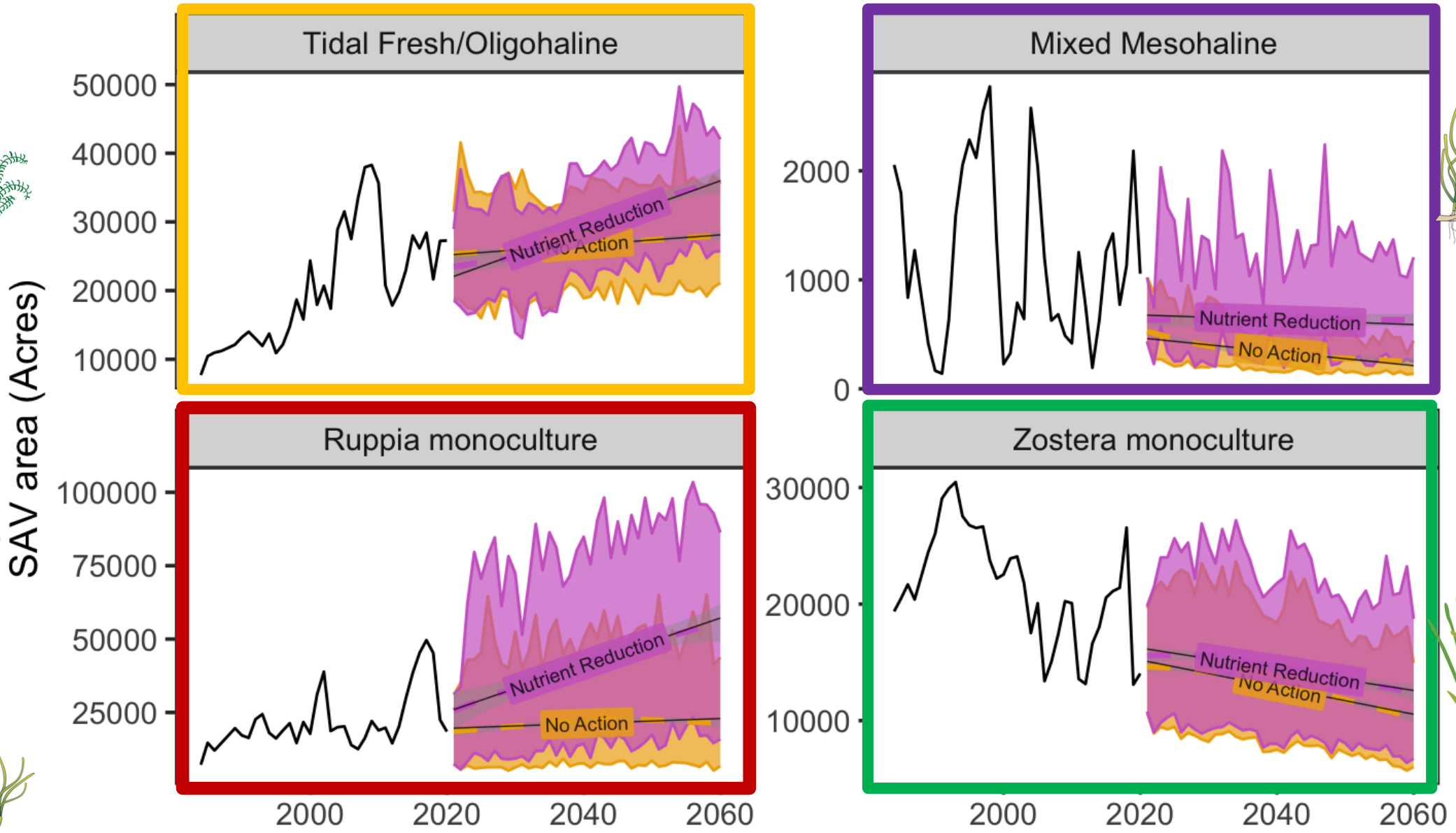
Step 3: SAV Community Climate change predictions| Major *Ruppia* benefits from Nutrient Reductions



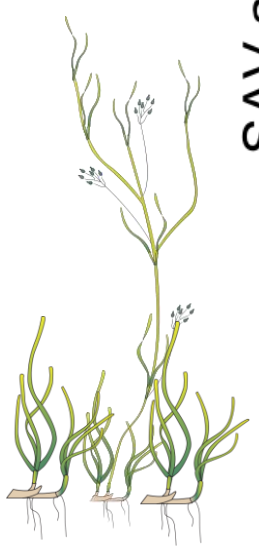
Step 3: SAV Community Climate change predictions|
New dominants respond most positively to nutrient reductions!

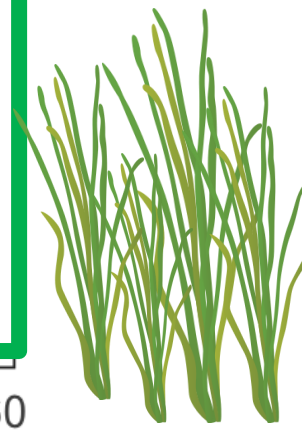


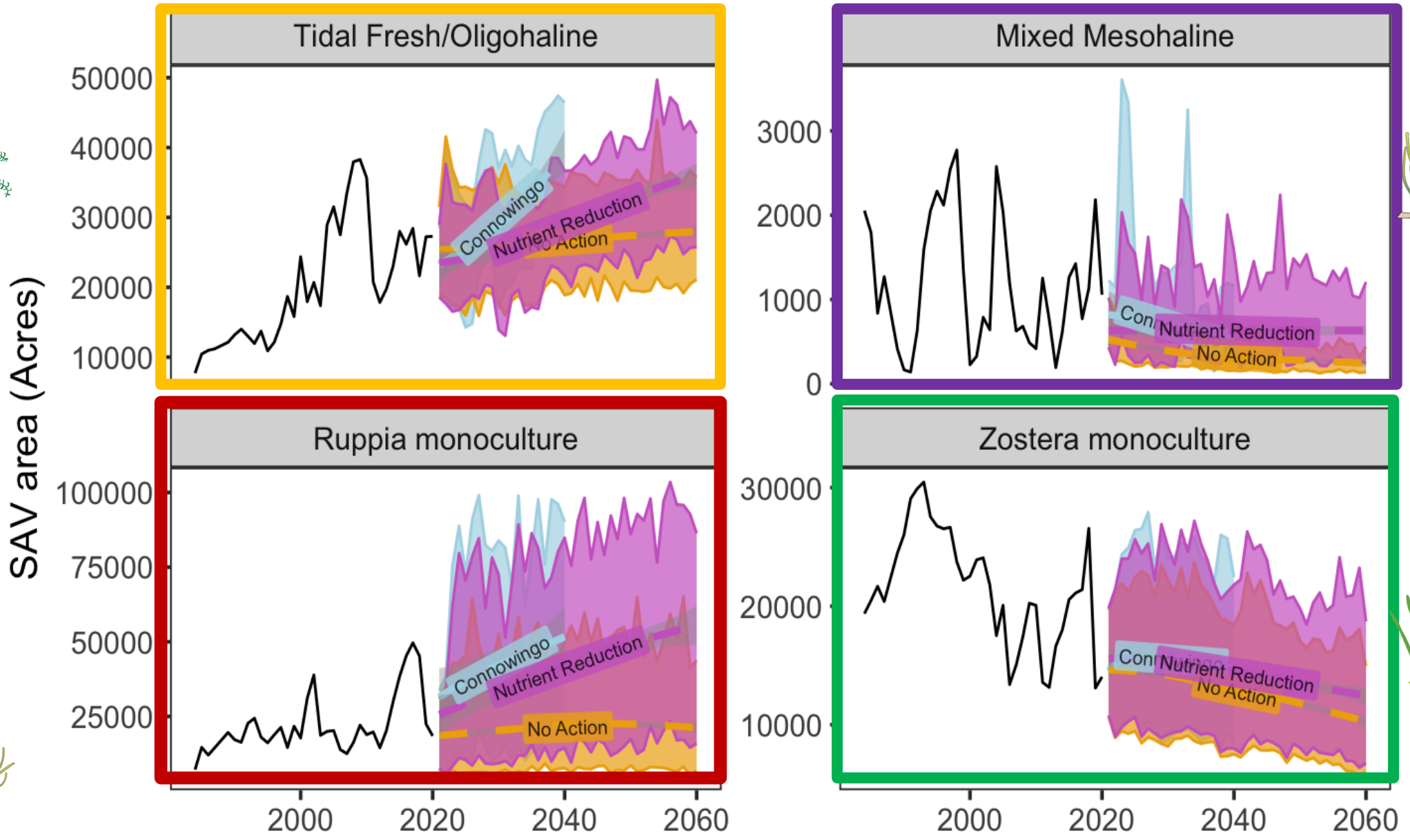




Step 3: SAV Community Climate change predictions|
New dominants respond most positively to ALL REDUCTIONS

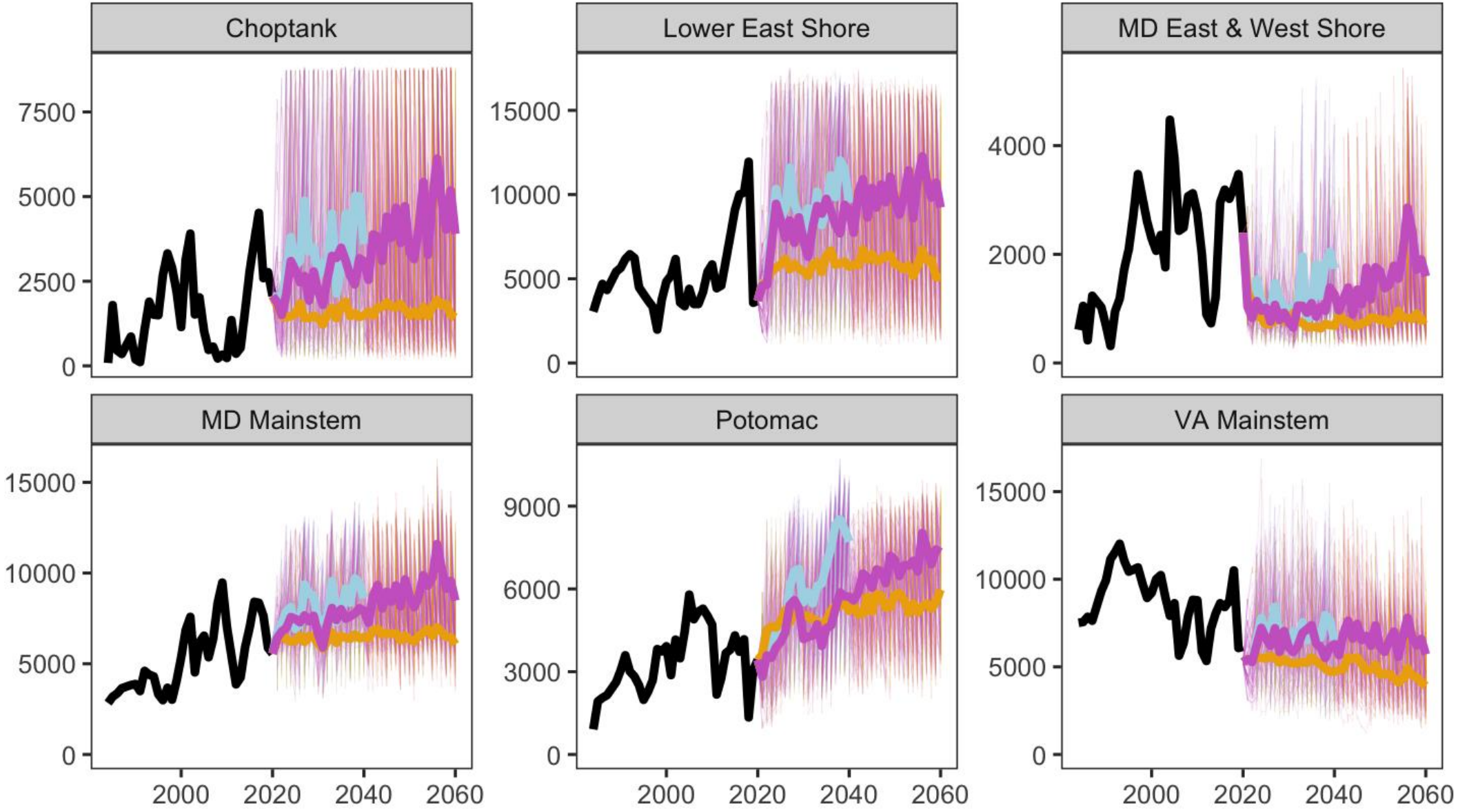






Step 3: Regional Climate change predictions|

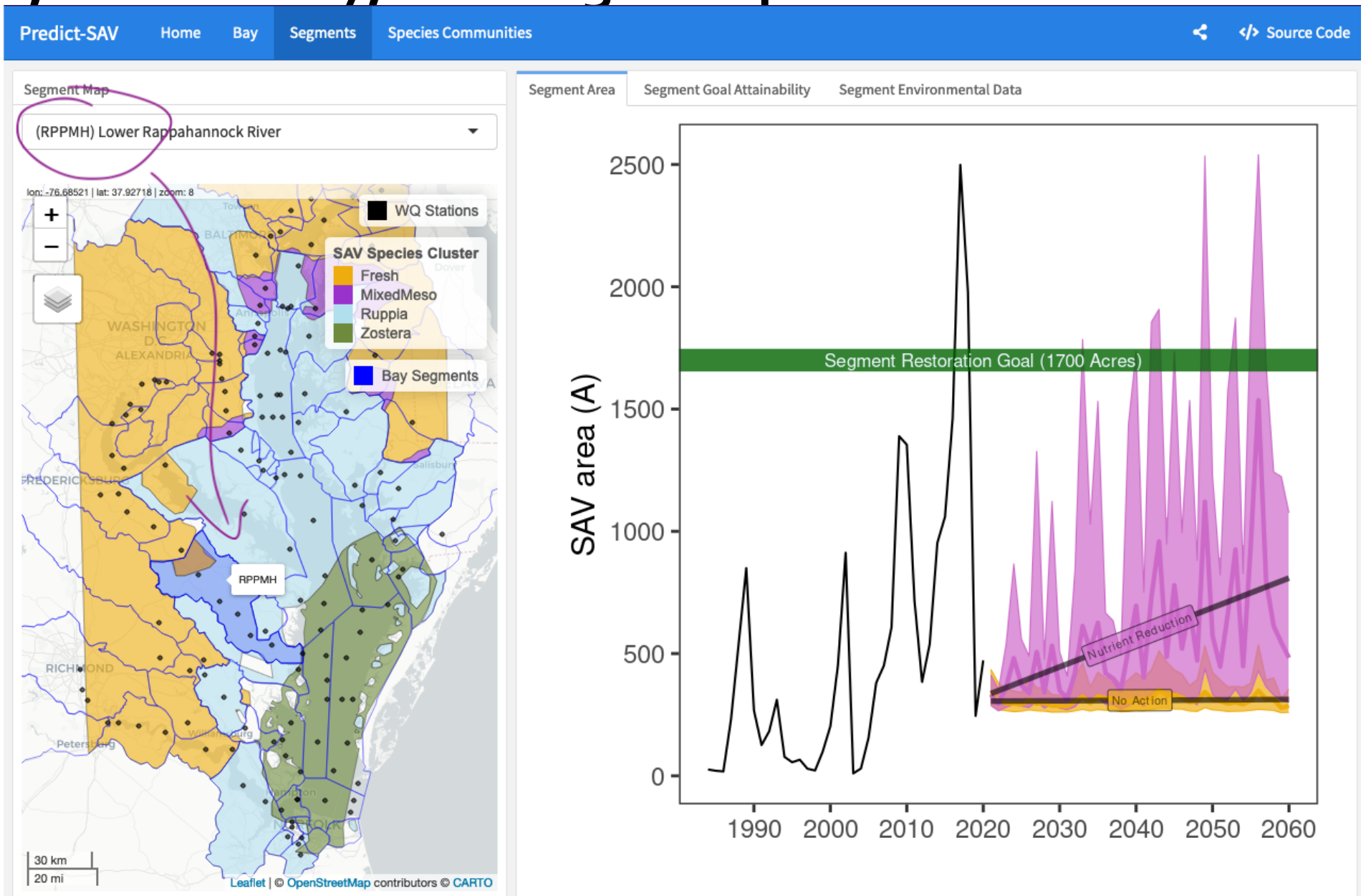
Gains in Choptank, Lower E Shore, MD mainstem offset losses in York/James



Step 3: Regional Climate change predictions|

Visualize Baywide, Community, and Regional predictions on our web app!

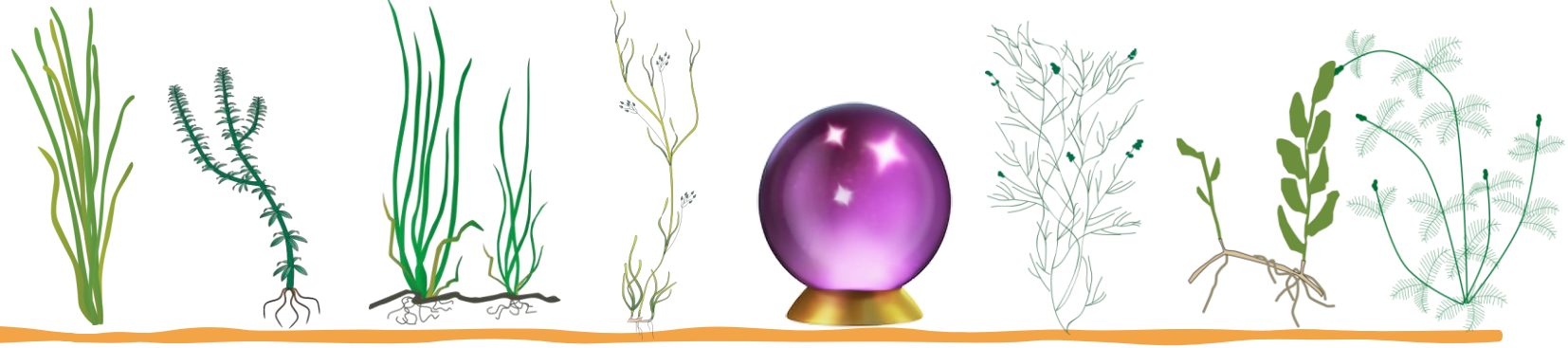
https://www.vims.edu/research/units/programs/sav/predicting-sav/index.php



Predicting the future in three steps

Step 1	Climate (temperature, precipitation) and human activities (nutrients) have reshaped species dominance in CB
Step 2	Temperature rise, precipitation variation are inevitable. Nutrient reductions may dictate future Bay conditions
Step 3	**Widgeongrass and freshwater dominance elevates the importance of future, further nutrient reductions for a vegetated Chesapeake Bay**

SUMMARY

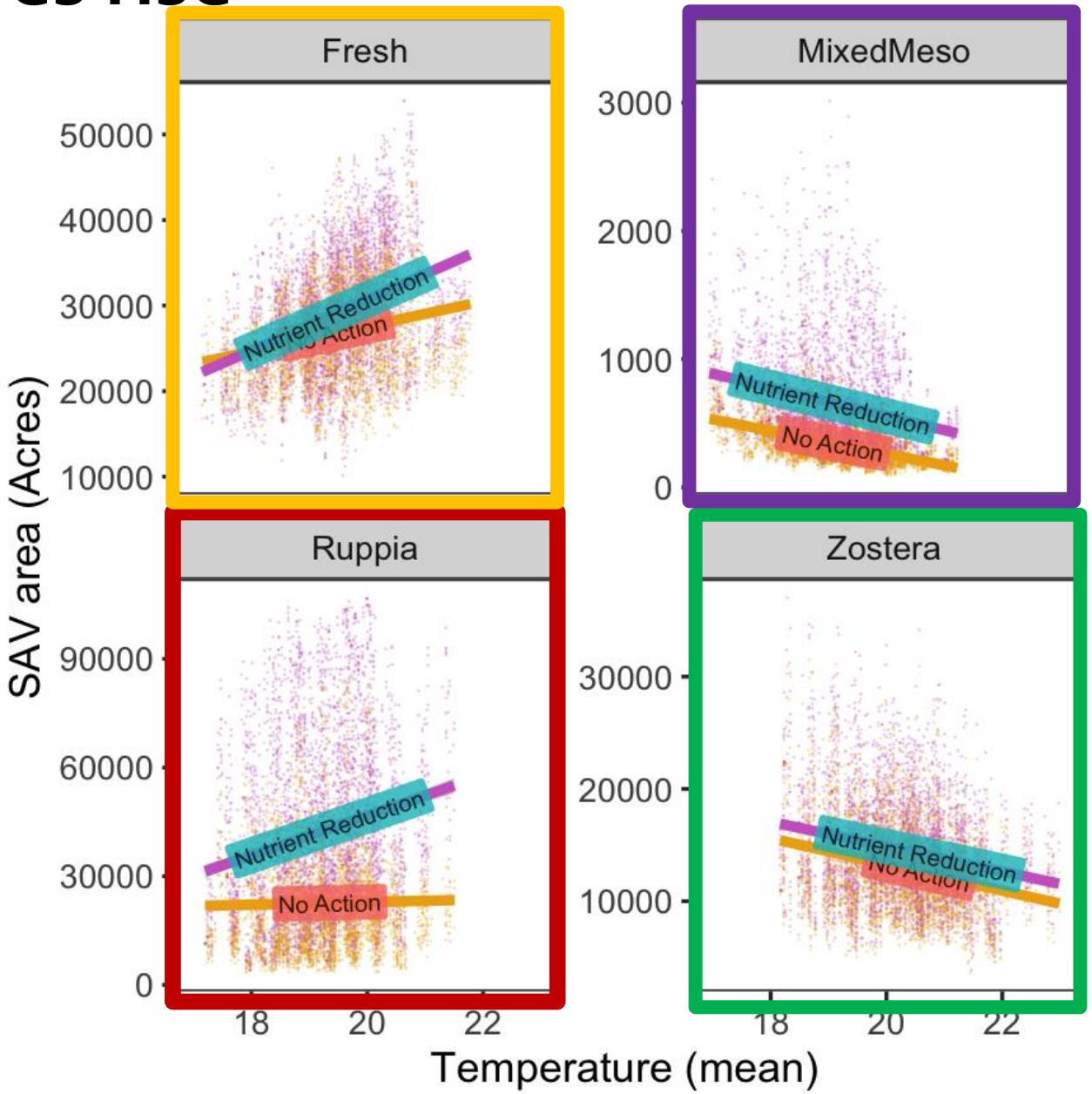


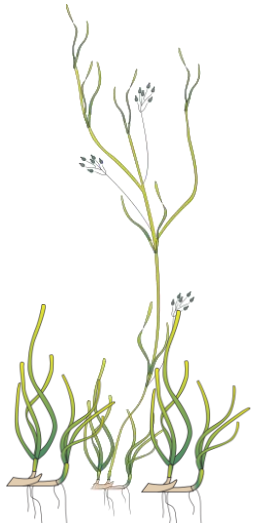
- **Temperature increases will widen the shift in dominant species, and management must adjust accordingly.**

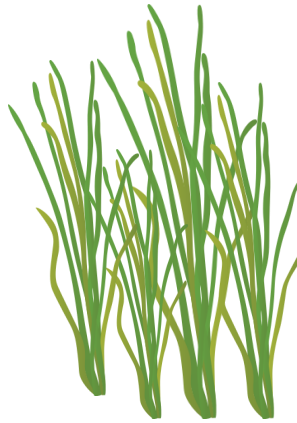
- **Nutrient reductions in the tidal fresh/oligohaline & *Ruppia* zones are essential, especially because the new dominants respond best to nutrient management**
  - Further reductions will have biggest effect in Potomac, MD mainstem, Choptank

- **Local/regional action offsets and prevents the effects of global climate change (!!)**
  - targeted nutrient management that benefits climate-tolerant species encourages continued recovery

SUMMARY | Nutrient reductions become more important as temperatures rise







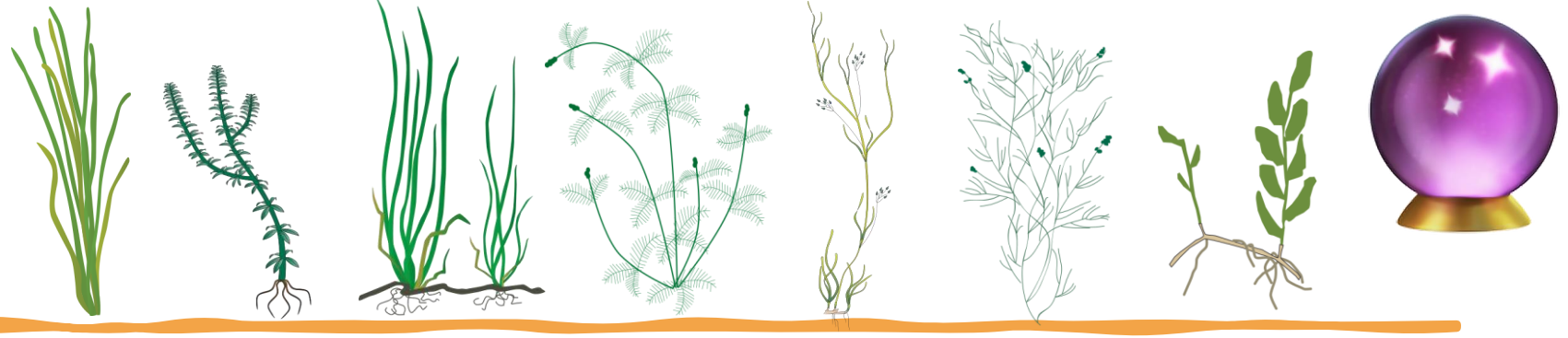
LESSONS LEARNED & WHAT WE DO NEXT

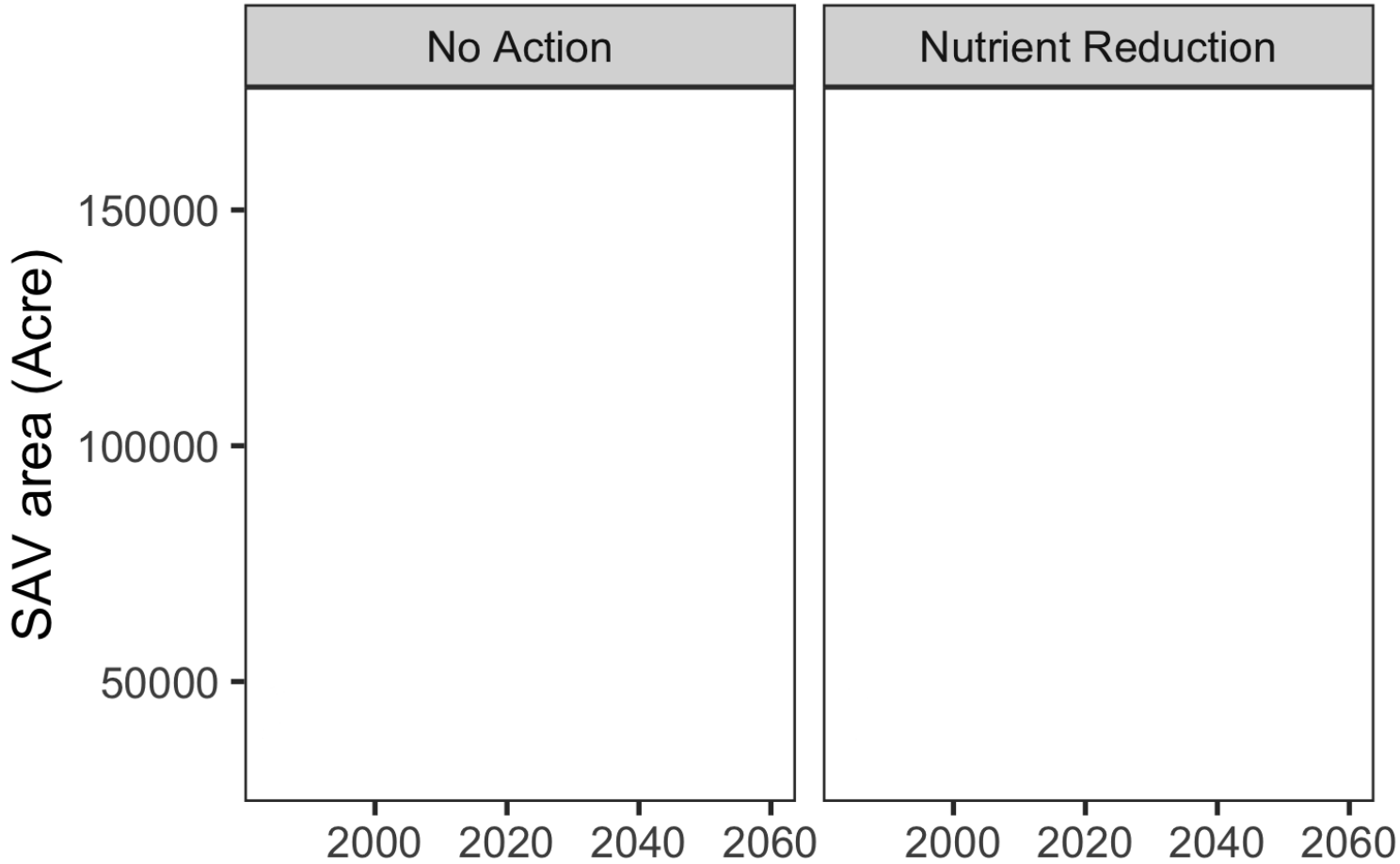
- **Segment goals, baywide goals… now we need community goals**
  - Importantly, community change monitoring (i.e., Sentinel program) to better define the community zones

- **We must start quantifying species shifts, food web shifts, and changes in fisheries**
  - Importantly, community change experiments and surveys (i.e., Sentinel program) to better track species abundance shifts

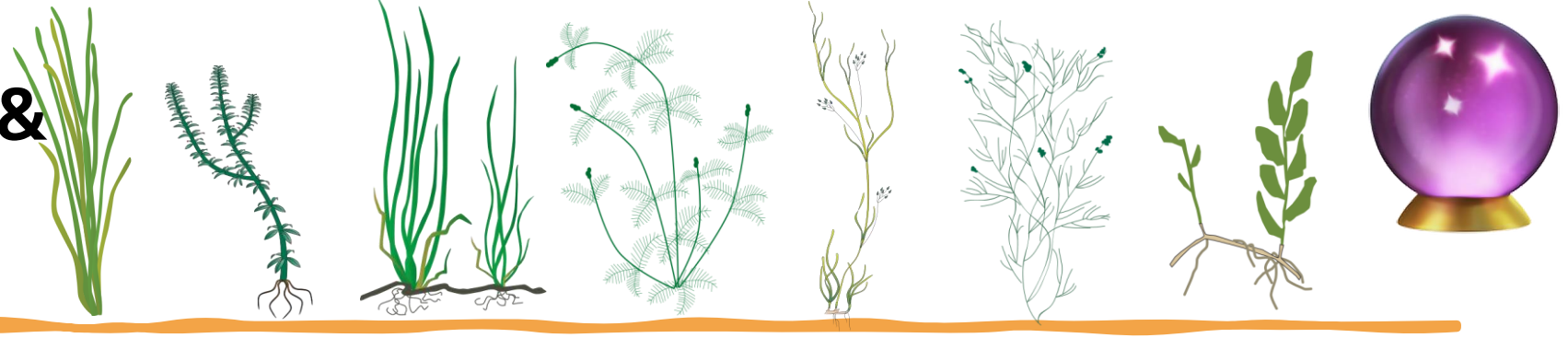
- **What would other regions need to do predictions like this, as more conditions and species change?**
  - Can we build a roadmap for data less-fortunate regions to get on track for climate change?

QUESTIONS?




No Action
Nutrient Reduction
SAV area (Acre)
150000
100000
50000
2000
2020
2040
2060
2000
2020
2040
2060

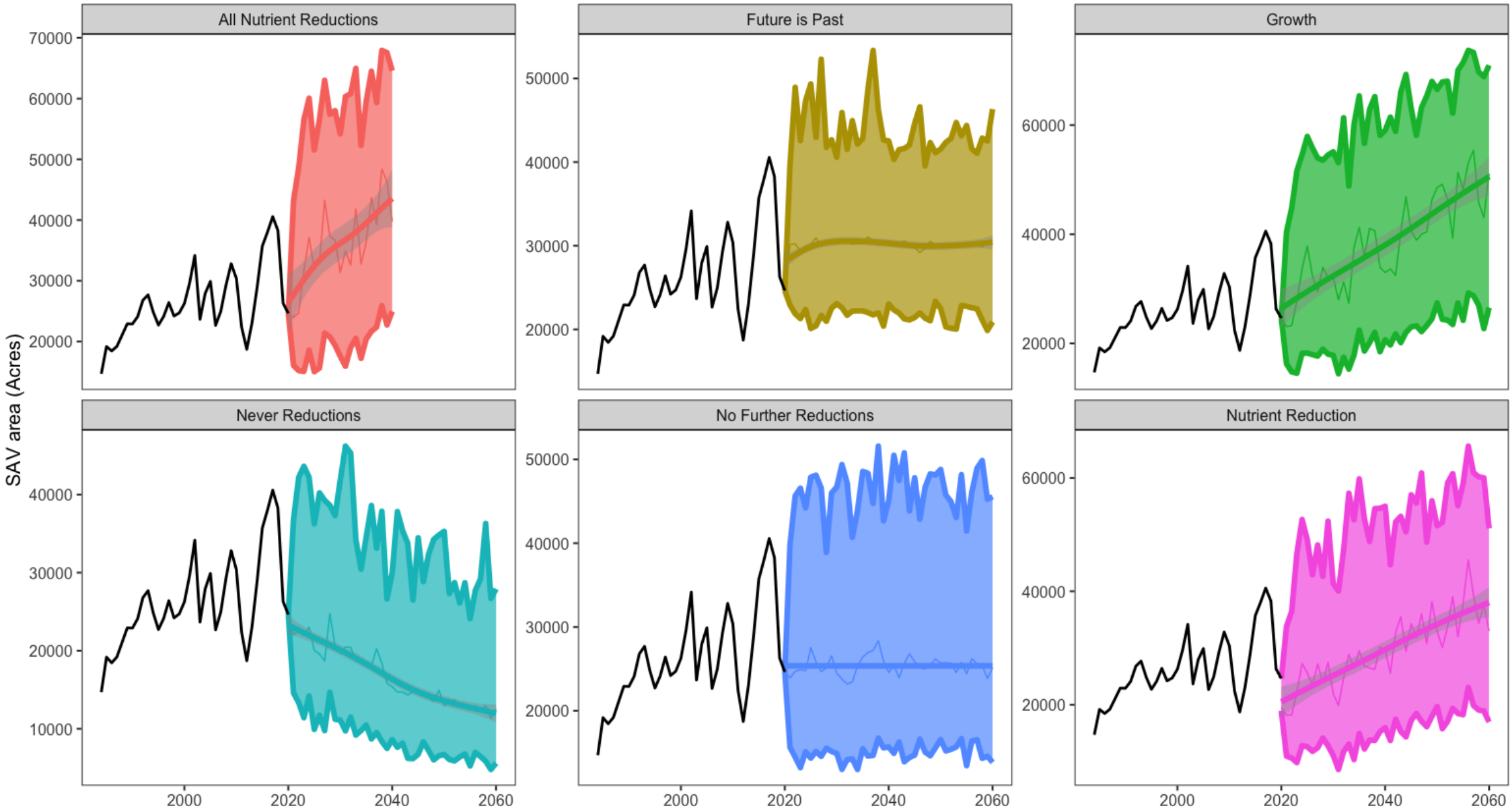
LESSONS LEARNED & WHAT WE DO NEXT



- Demonstration of our web-based app to visualize climate change predictions across the Chesapeake Bay

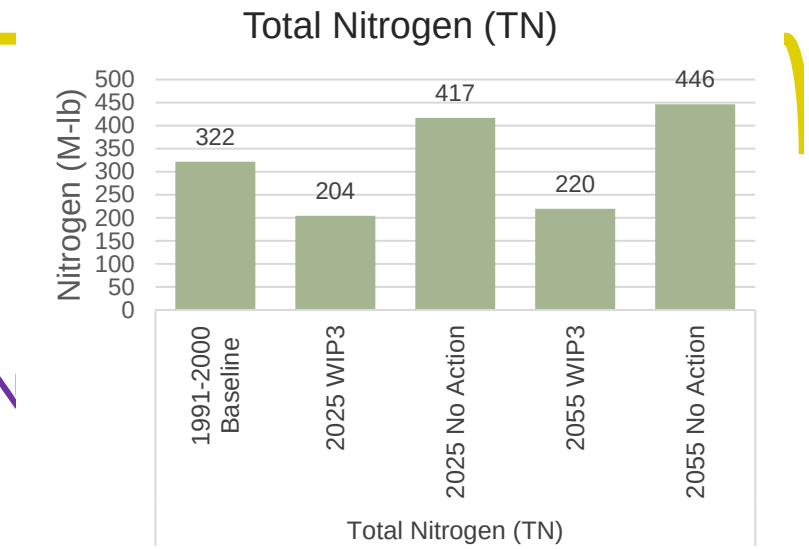
- https://www.vims.edu/research/units/programs/sav/predicting-sav/index.php

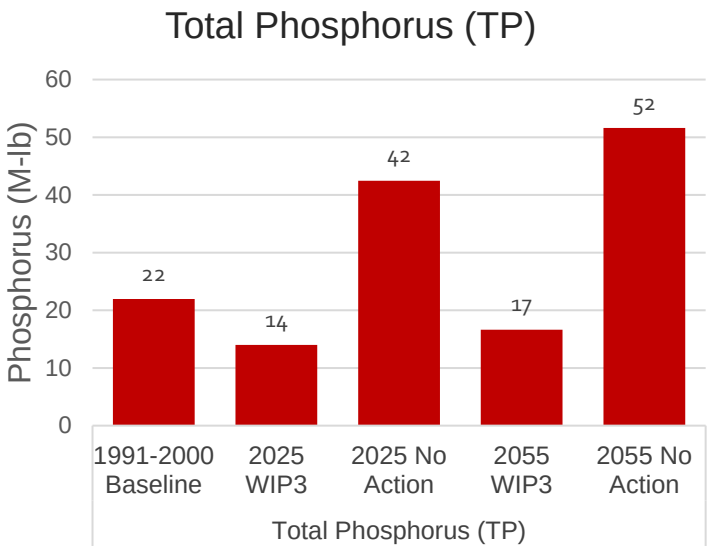
- https://vims-sav.shinyapps.io/predict-sav/#section-segments

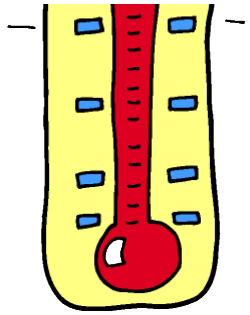

All Nutrient Reductions
Future is Past
Growth
Never Reductions
No Further Reductions
Nutrient Reduction
SAV area (Acres)
70000
60000
50000
40000
30000
20000
10000
2000
2020
2040
2060

Step 2: Two future scenarios from CBP Modeling data

No Further Action







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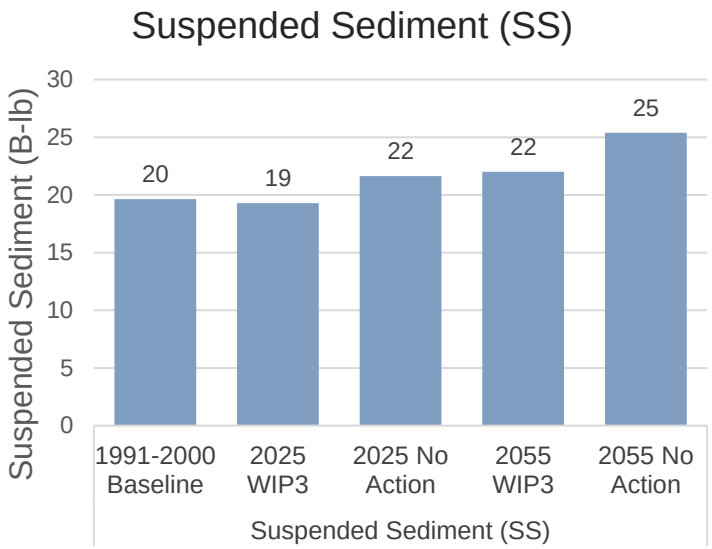
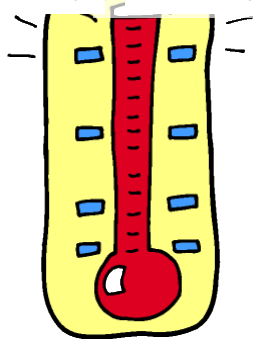
Temperature rise **Rainfall variability**

Nutrient Reductions





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Temperature rise **Rainfall variability**