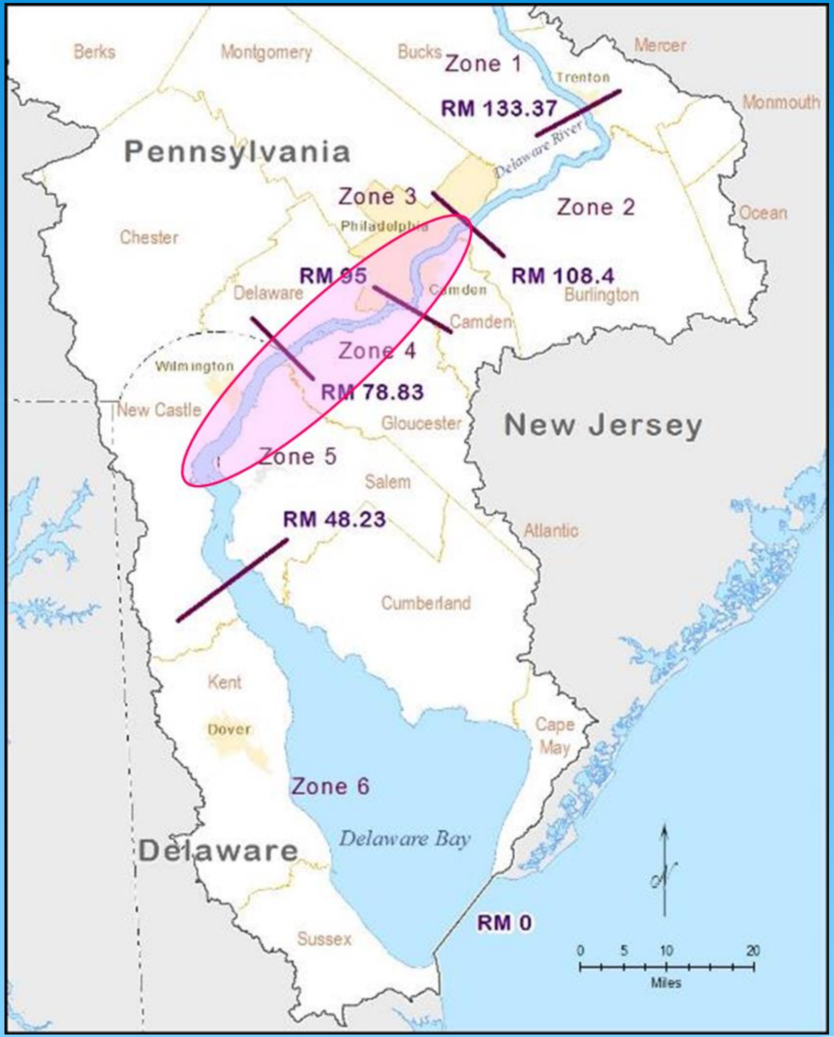
Analysis of Attainability Progress Update

Water Quality Advisory Committee

July 14, 2022



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Discussion Items

- Big Picture – Analysis of Attainability
- Simulation Results
  - Design conditions
    - Actual and Permitted flows
  - Initial simulations
    - Effluent nitrogen reduction scenarios
    - Effluent dissolved oxygen & CBOD impact
    - CSO impact
    - Tributary and MS4 impact
- Relationship between aquatic life use and dissolved oxygen
  - "Deeper dive" – Evaluation of thresholds for Atlantic Sturgeon
  - Basis for fish suitability determinations
  - Methodology to incorporate all eight DO-sensitive species

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What is this "Analysis of Attainability"?

Regulatory basis

- Aquatic life use defined as the degree of propagation associated with a given dissolved oxygen condition

Purpose

- **Highest Attainable Dissolved Oxygen (HADO) condition to be determined based on feasibility, costs, and benefits in the fish maintenance area**

Outcome

- Revised designated use will be the enhanced degree of propagation associated with the HADO condition

Analysis of Attainability (Regulatory basis, Purpose)

Rulemaking (Outcome)

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Review:
Elements of “Analysis of Attainability”

Core modeling elements

- Design condition
  - Permitted loads under critical conditions
  - Provides a baseline against which to compare future scenarios
- Test Scenarios
  - Source sensitivity scenarios
  - Load reduction scenarios
- Metrics to compare scenarios
  - Basis to compare one scenario with another
  - Dissolved oxygen metrics

Subsequent elements for future discussion

- Selection of candidate scenarios
- Characterization of costs and benefits
  - Systemwide characterization
  - Benefits can be characterized based on DO improvement and increase in estuary value
- Affordability evaluation
  - Facility-specific
  - May influence scenario selection and/or compliance schedule

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Simulation Results

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Design Condition (Baseline) Scenarios

Series Label	Description
2D 2012 Corroboration	2D 2012 corroboration hindcast reflecting actual conditions
2D 2012 Dredged	2D 2012 corroboration hindcast reflecting dredged condition
3D-Baseline (permitted flows)	3D Design Condition with permitted WWTP flows
3D-Baseline (actual flows)	3D Design Condition with actual WWTP flows
3D Actual Loads with Permitted Flows	3D Design Condition comparison: actual WWTP loads and permitted WWTP flows
2D-Baseline (permitted flows)	2D Design Condition with permitted WWTP flows

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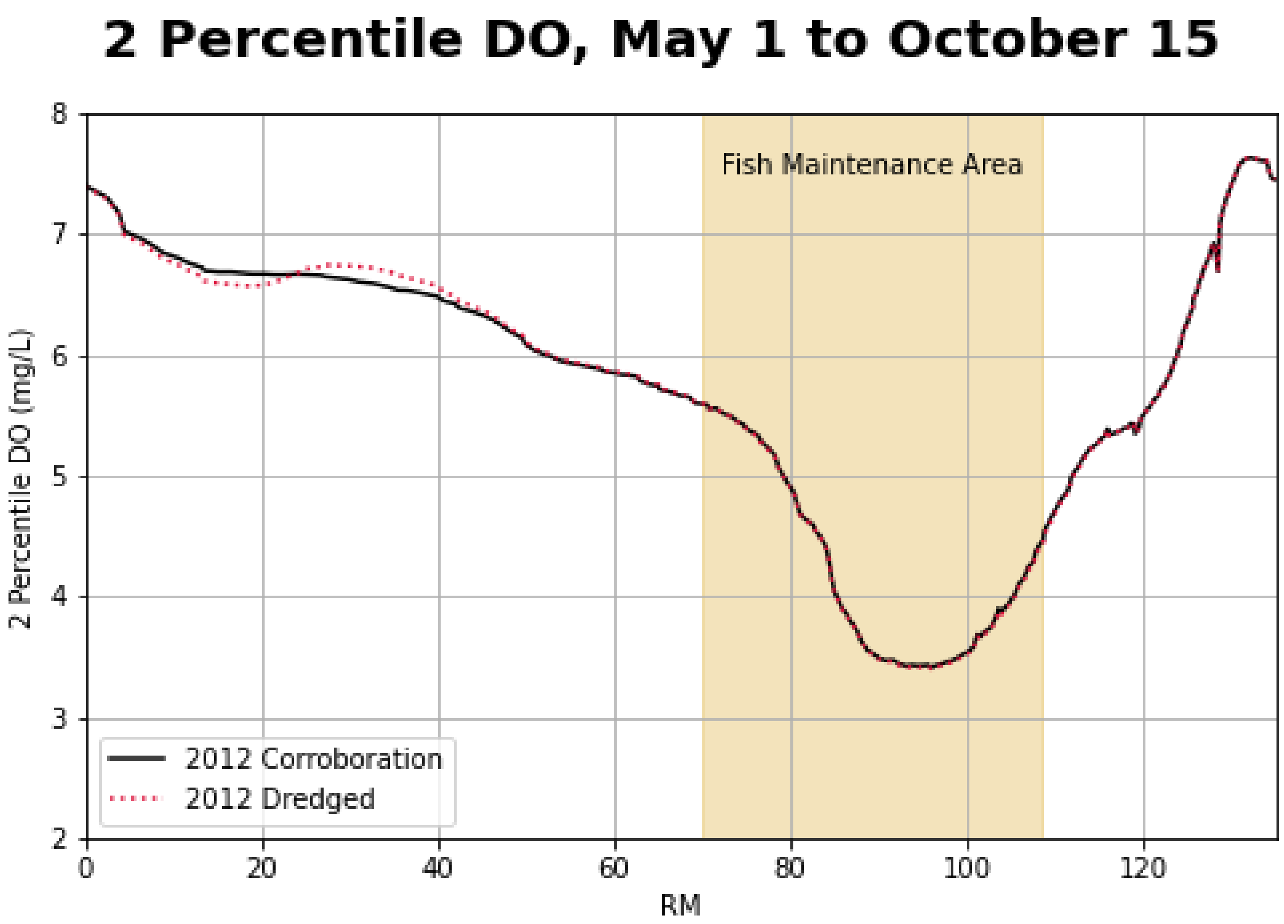
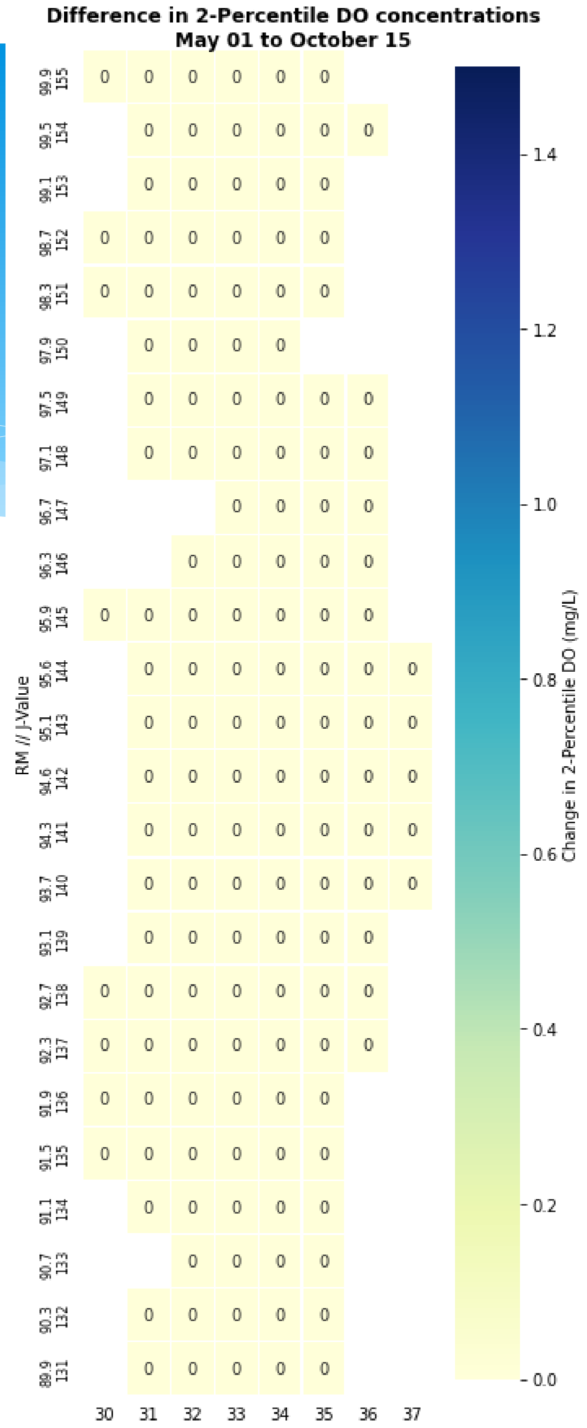
Test Scenarios

Series Label	Description
2D-Permitted w/ Tier1 NH_3-N = 1.5	2D-DesignPermitted w/ Tier 1 NH_3-N = 1.5 mg/L (difference added to NO_3-N)
2D-Actual w/ Tier1 NH_3-N = 1.5	2D-DesignActual w/ Tier 1 NH_3-N = 1.5 mg/L (difference added to NO_3-N)
2D-Permitted w/ Tier2 NH_3-N = 1.5	2D-DesignPermitted w/ Tier 2 NH_3-N = 1.5 mg/L (difference added to NO_3-N)
2D-Permitted w/ Tier3 NH_3-N = 1.5	2D-DesignPermitted w/ Tier 3 NH_3-N = 1.5 mg/L (difference added to NO_3-N)
2D-Permitted w/ Tier1 NH_3-N = 10	2D-DesignPermitted w/ Tier 1 NH_3-N = 10 mg/L (difference added to NO_3-N)
2D-Permitted w/ Tier1 NH_3-N = 5.0	2D-DesignPermitted w/ Tier 1 NH_3-N = 5.0 mg/L (difference added to NO_3-N)
2D-Permitted w/ Tier1 TN = 4.0	2D-DesignPermitted w/ Tier 1 TN = 4.0 mg/L (NH_3-N = 1.5; Org-N = 1.0; NO_3-N = 1.5)
2D-Permitted w/ CCMUA NH_3-N = 1.5	2D-DesignPermitted w/ Camden WPCF NH_3-N = 1.5 mg/L (difference added to NO_3-N)
2D-Permitted w/ PWD-SE NH_3-N = 1.5	2D-DesignPermitted w/ PWD-SE NH_3-N = 1.5 mg/L (difference added to NO_3-N)
2D-Permitted w/ PWD-SW NH_3-N = 1.5	2D-DesignPermitted w/ PWD-SW NH_3-N = 1.5 mg/L (difference added to NO_3-N)
2D-Permitted w/ PWD-NE NH_3-N = 1.5	2D-DesignPermitted w/ PWD-NE NH_3-N = 1.5 mg/L (difference added to NO_3-N)
2D-Permitted w/ WWTP DO $\geq$ 6.0	2D-DesignPermitted w/ effluent DO not less than 6 mg/L
2D-Permitted w/ WWTP CBOD = 10	2D-DesignPermitted w/ effluent CBOD = 10 mg/L
2D-Permitted w/ CSO NH_3-N reduced 85%	2D-DesignPermitted w/ CSO NH_3-N reduced by 85%
2D-Permitted w/ CSO CBOD reduced 85%	2D-DesignPermitted w/ CSO CBOD reduced by 85%
2D-Permitted w/ NPS and MS4 removed	2D-DesignPermitted w/ NH_3-N, Det-N, Det-C, and CBOD set to zero for all direct NPS & MS4

Impact of Dredging on DO

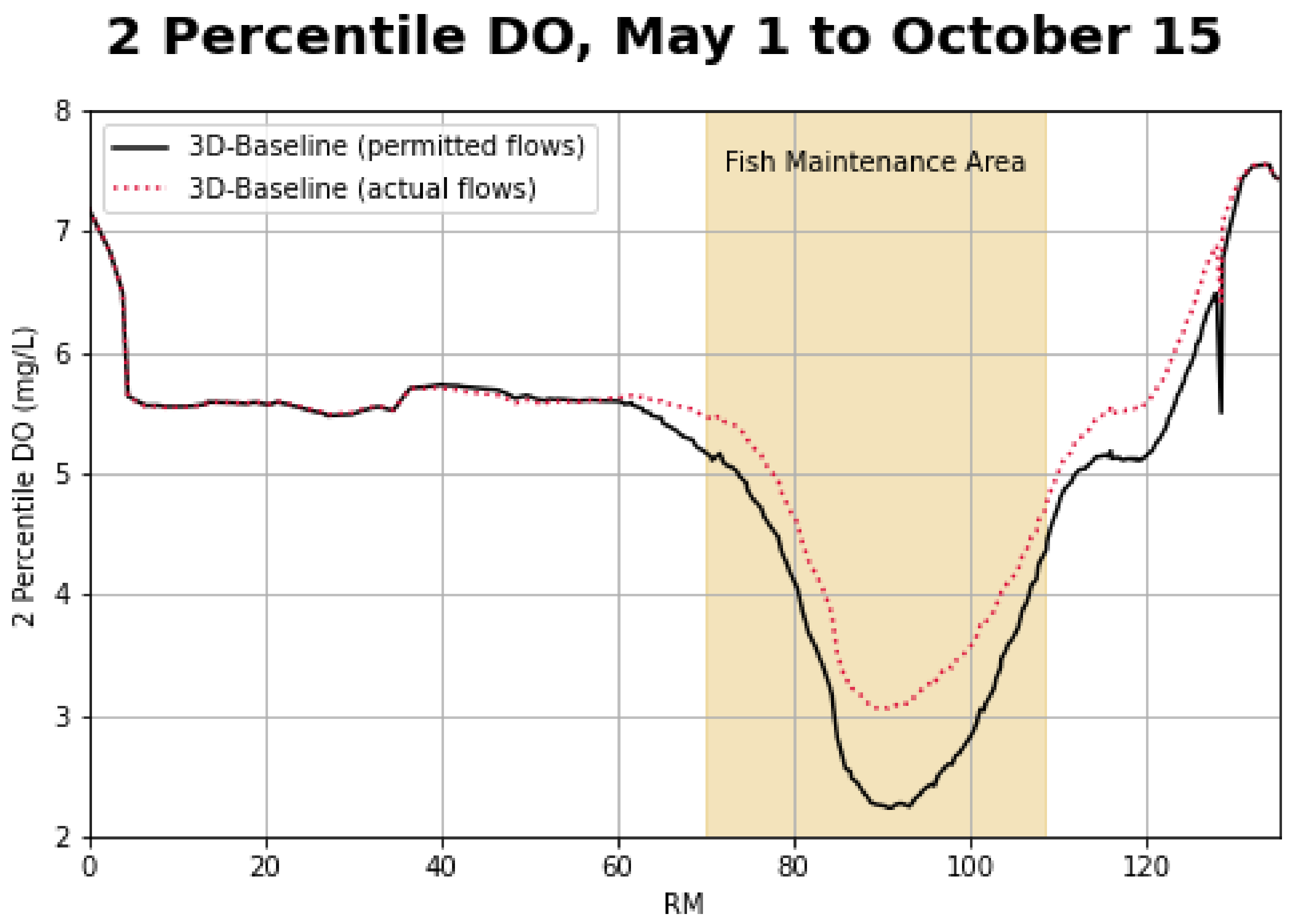
2012 hindcast with and without dredging

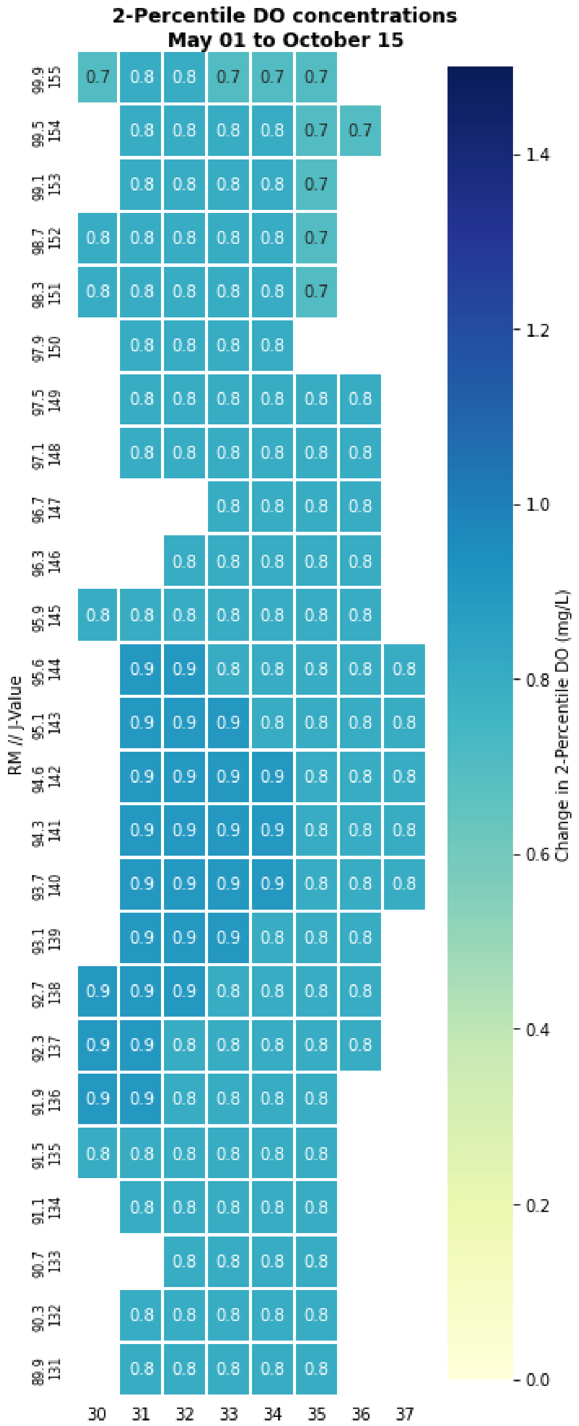




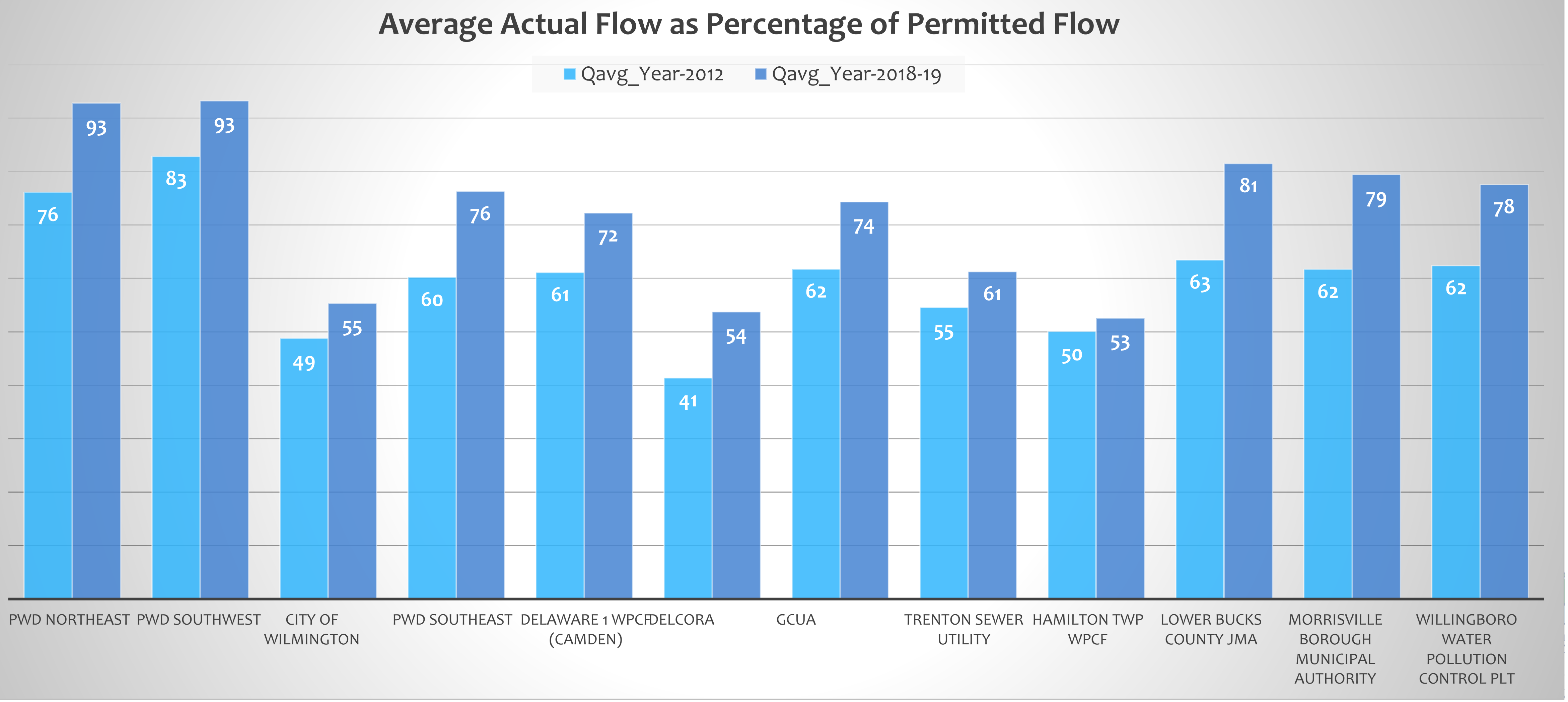
Design Condition Simulations

Permitted and Actual Flows



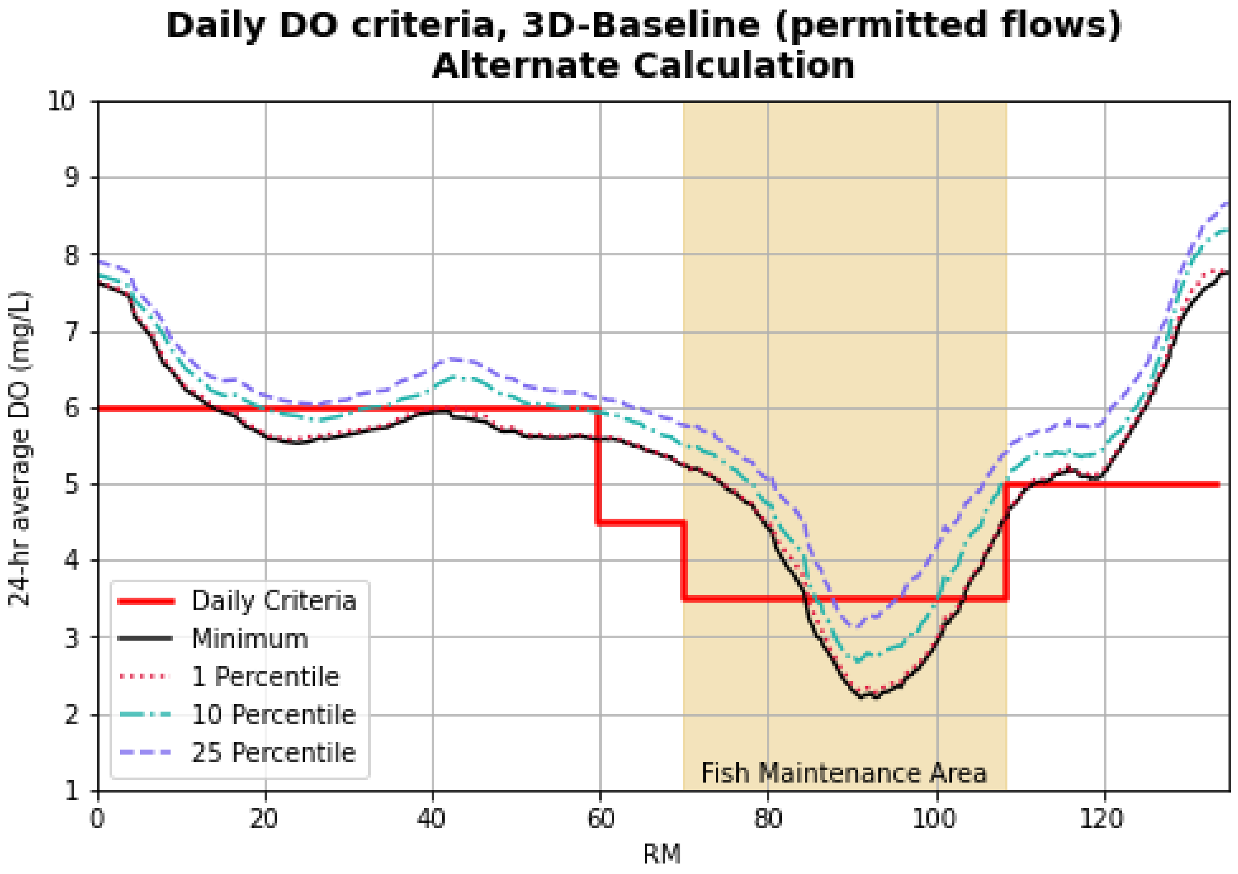


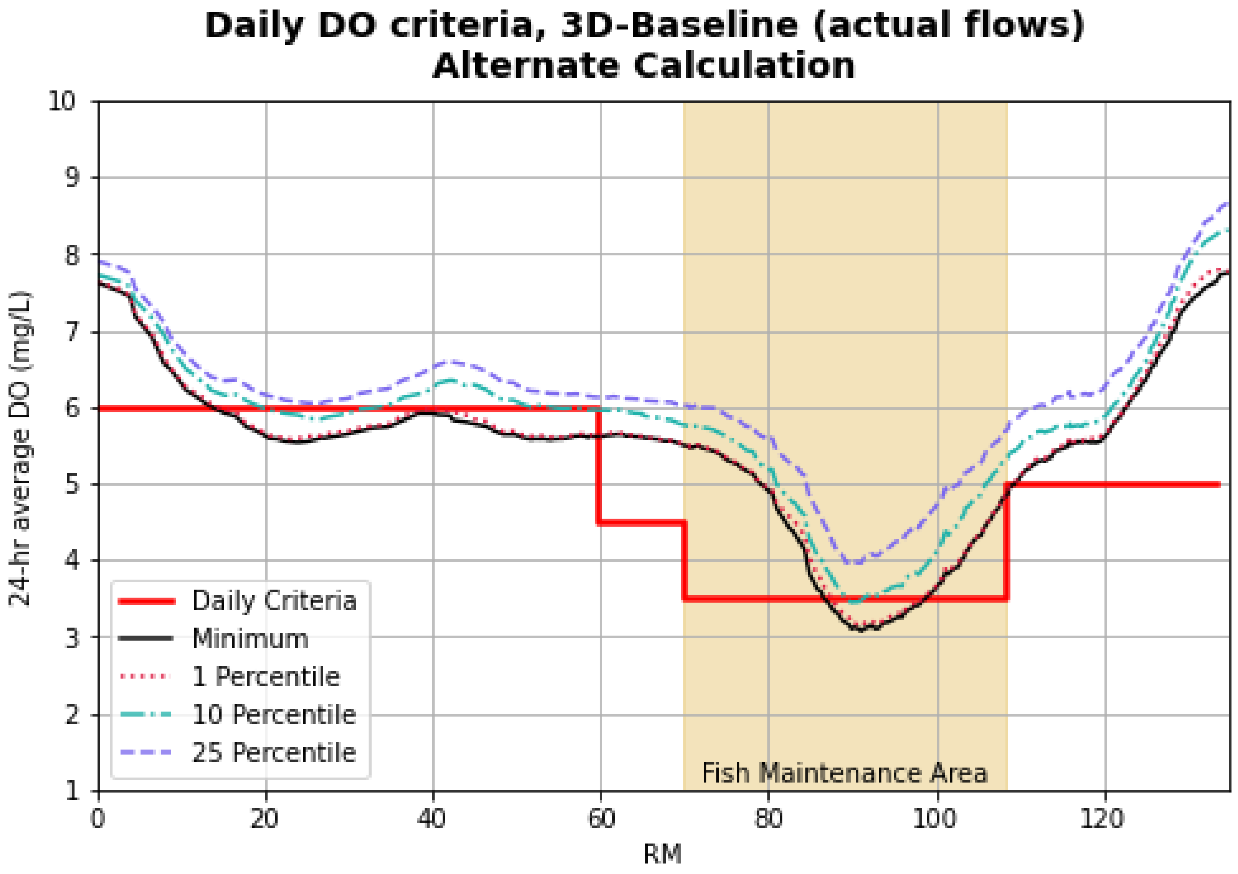
Difference between actual and permitted flows is exacerbated in dry 2012 year



Design Condition Simulations against 24-hr Criteria

Permitted and Actual Flows





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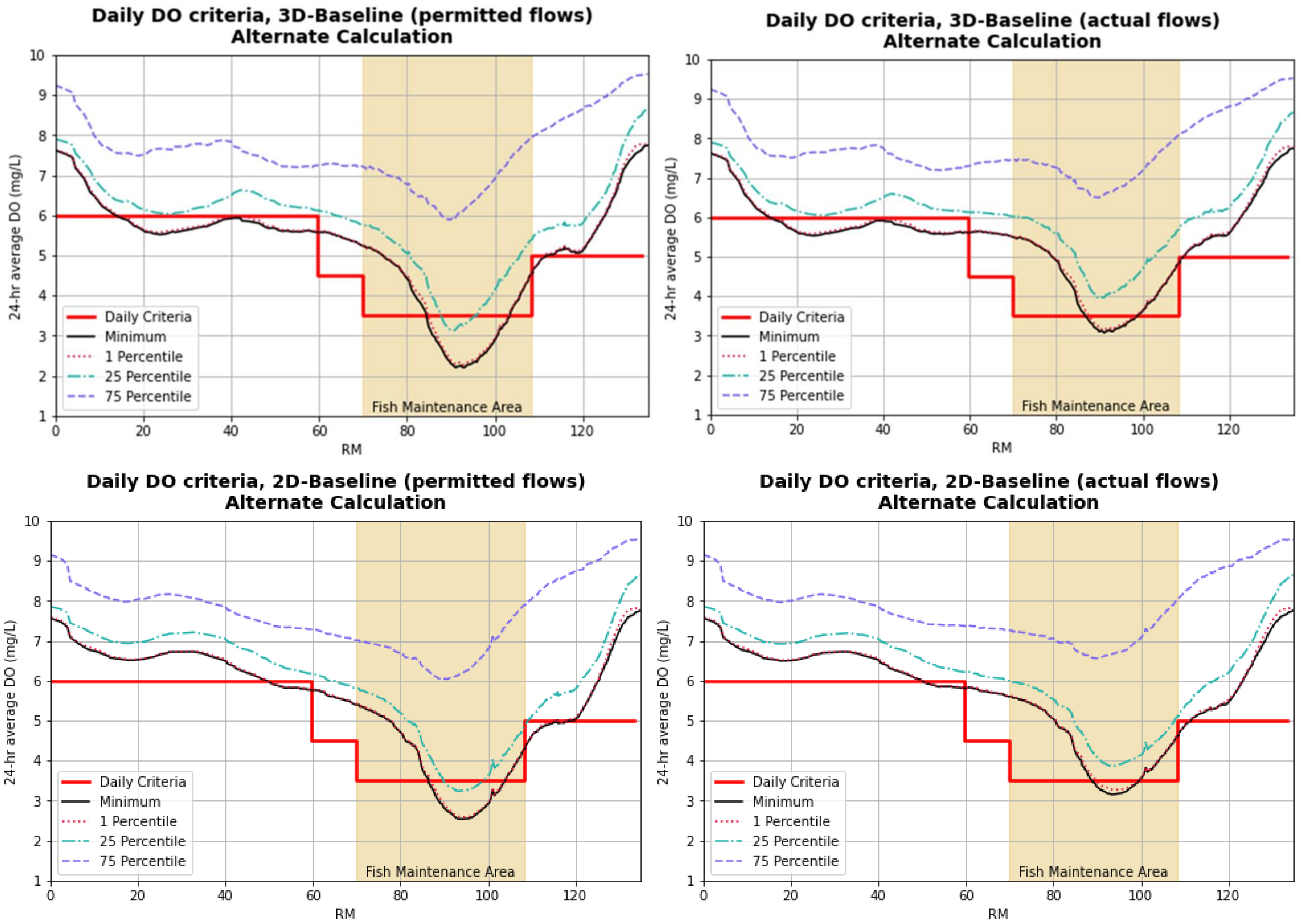
Design Condition Simulations against 24-hr Criteria (3D vs. 2D)



<u>Calculation method</u>

1. Calculate 24-hr average DO time series at each cell.
2. Calculate X percentile value at each cell.
3. Within each J cross-section, take the median.

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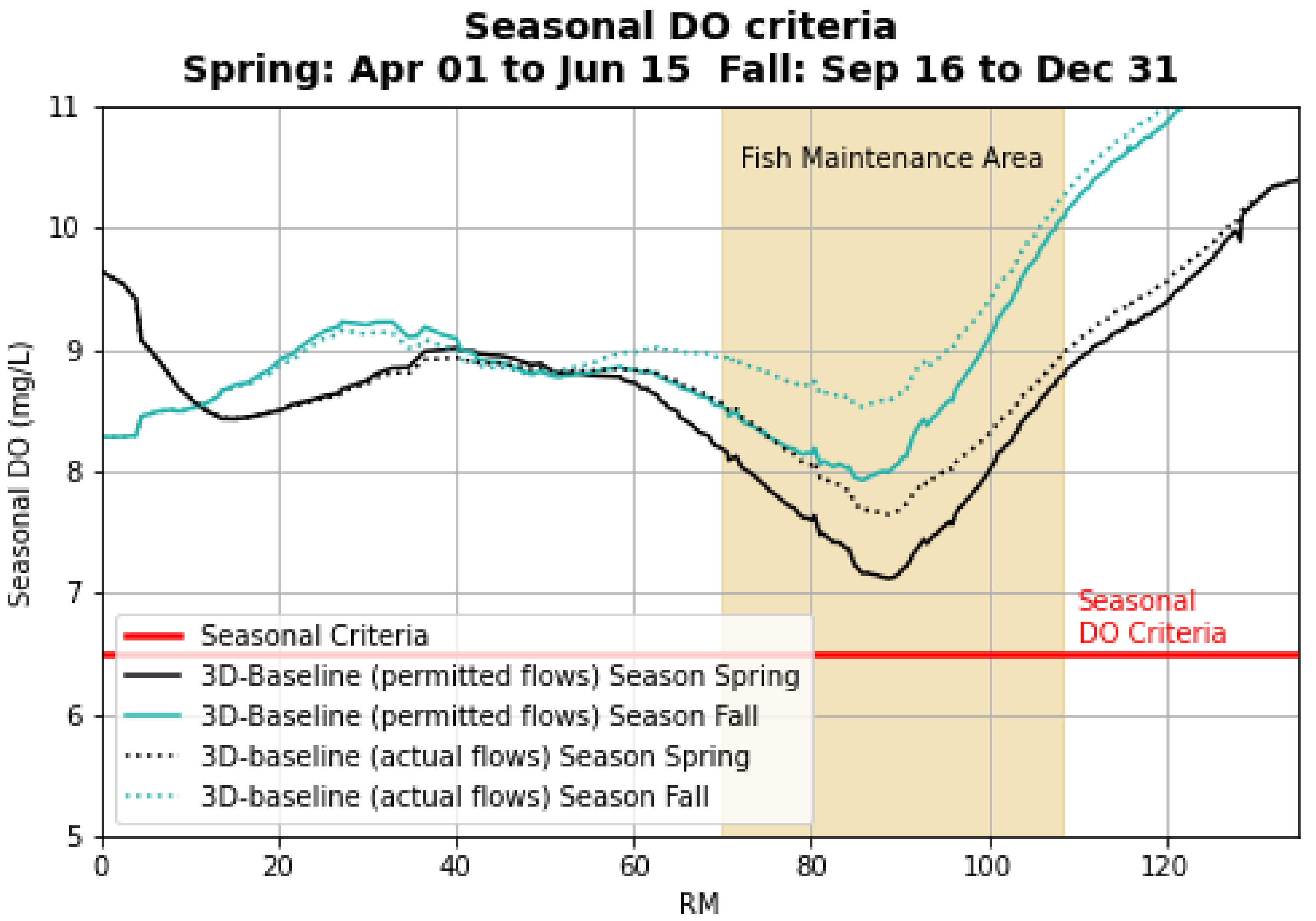
Comparison of Design Condition against Seasonal DO Criteria



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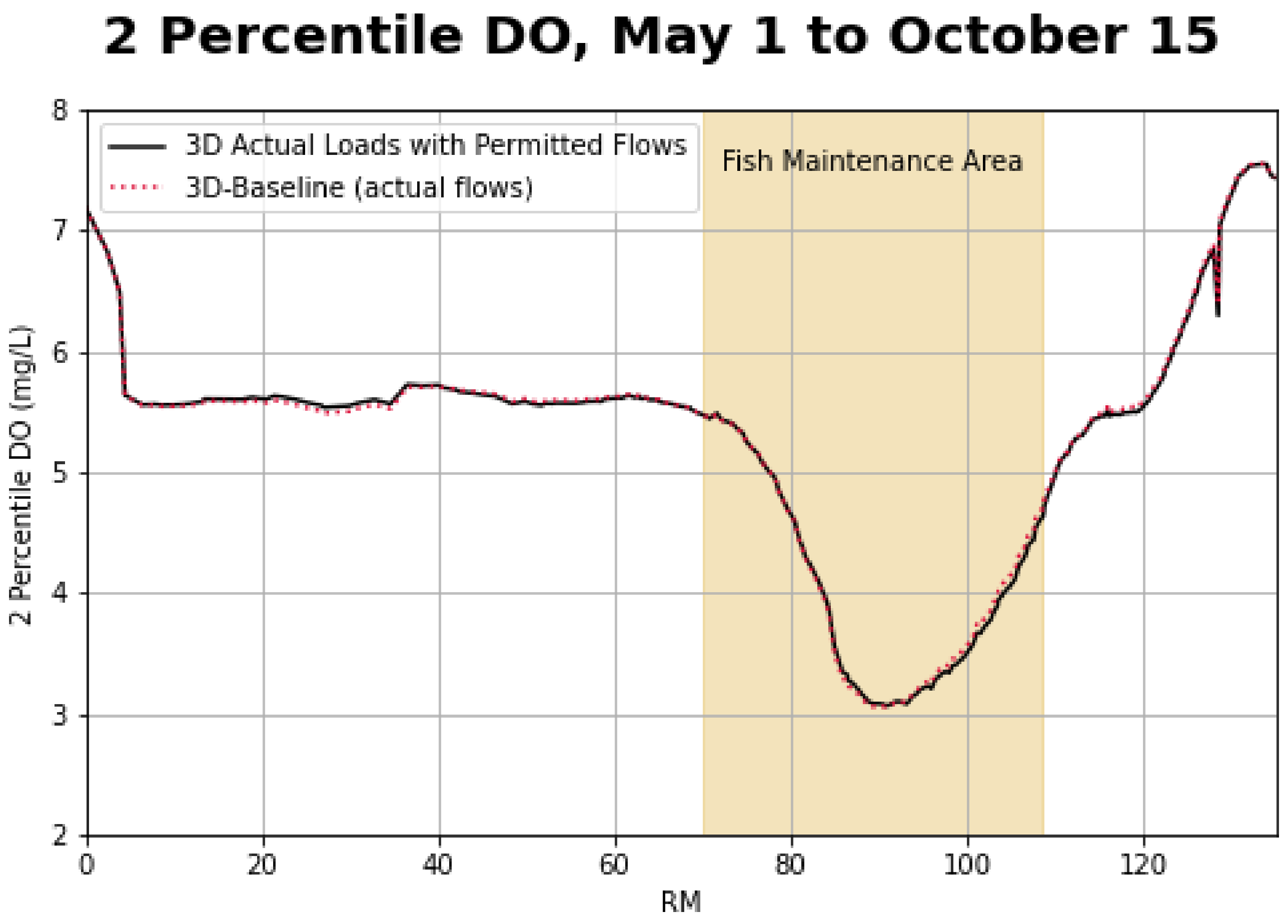
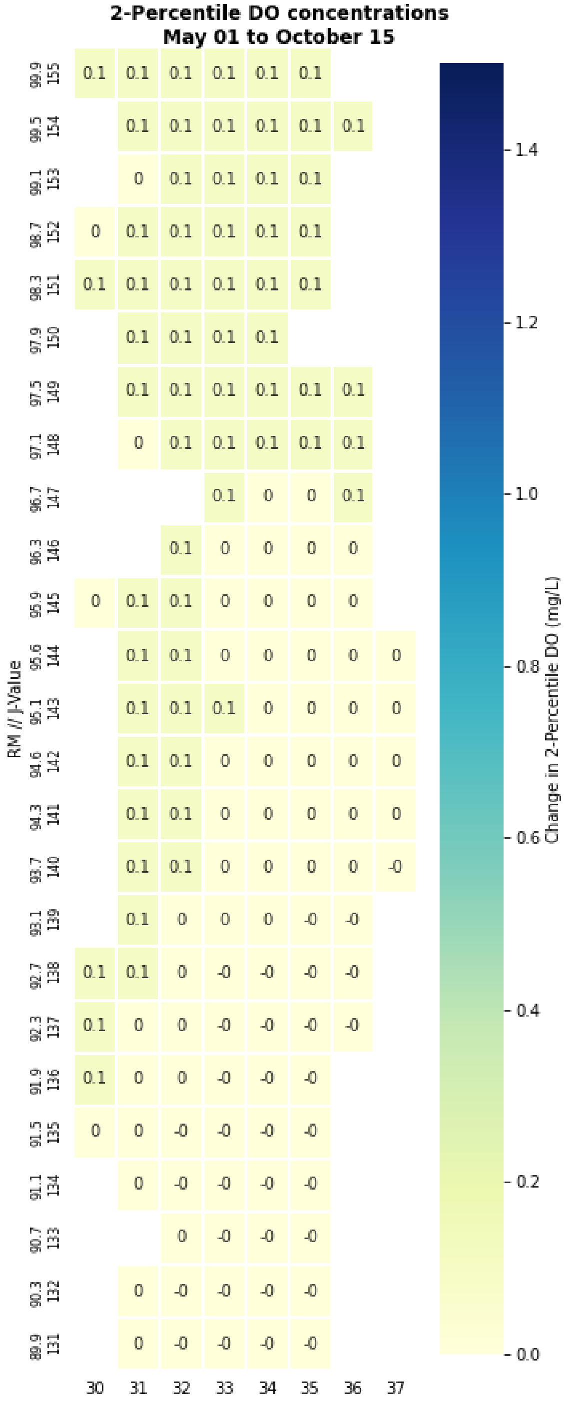
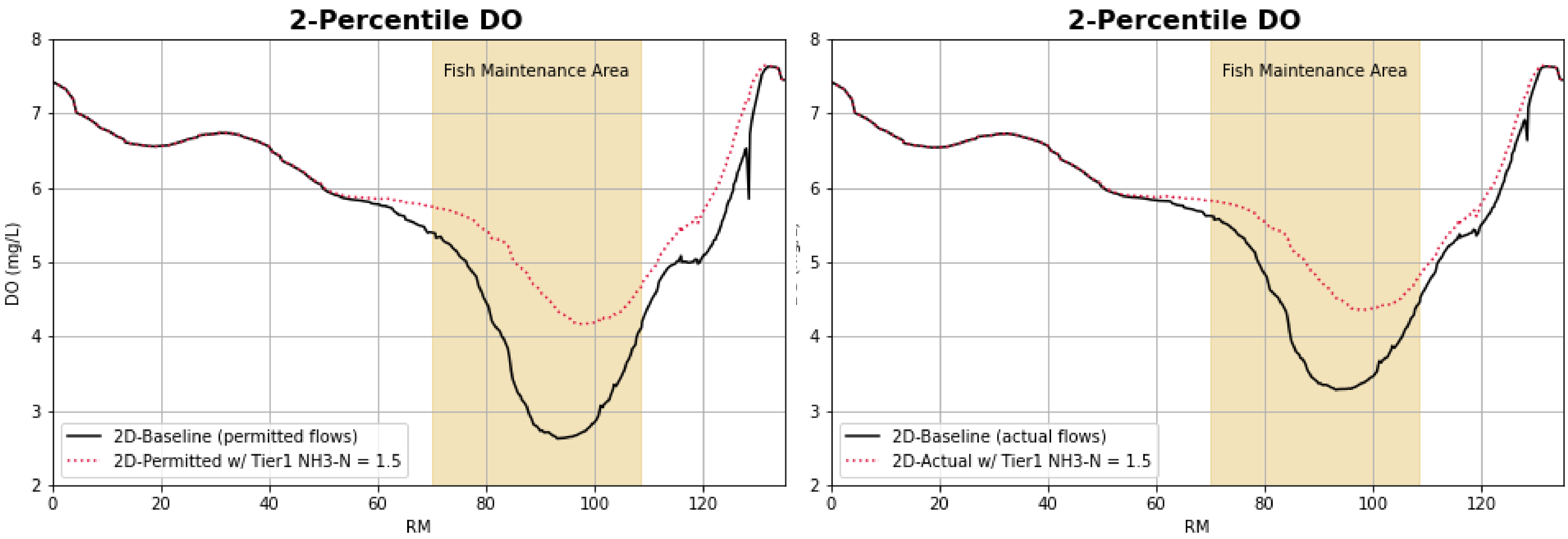
Impact of Effluent Flow on DO

Same loads delivered in Permitted and Actual Flows



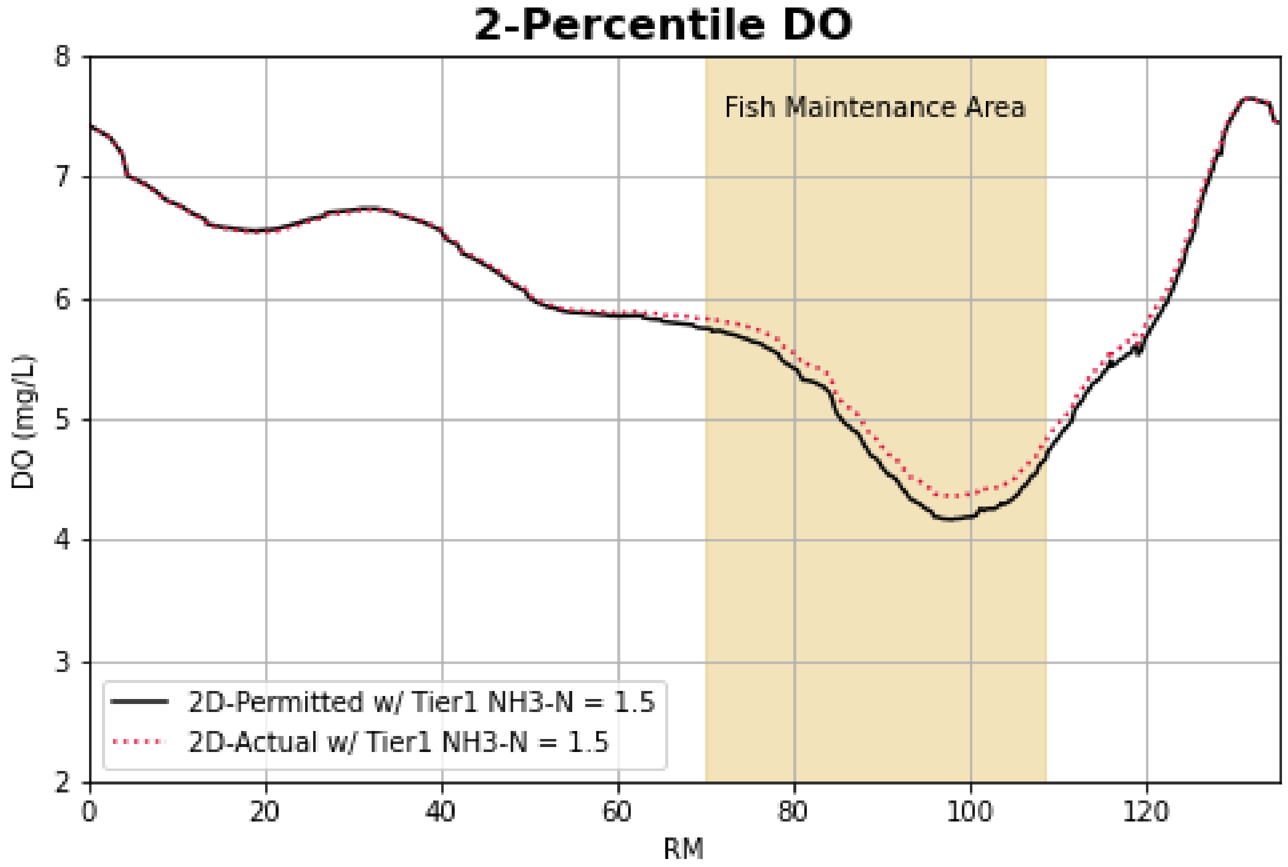


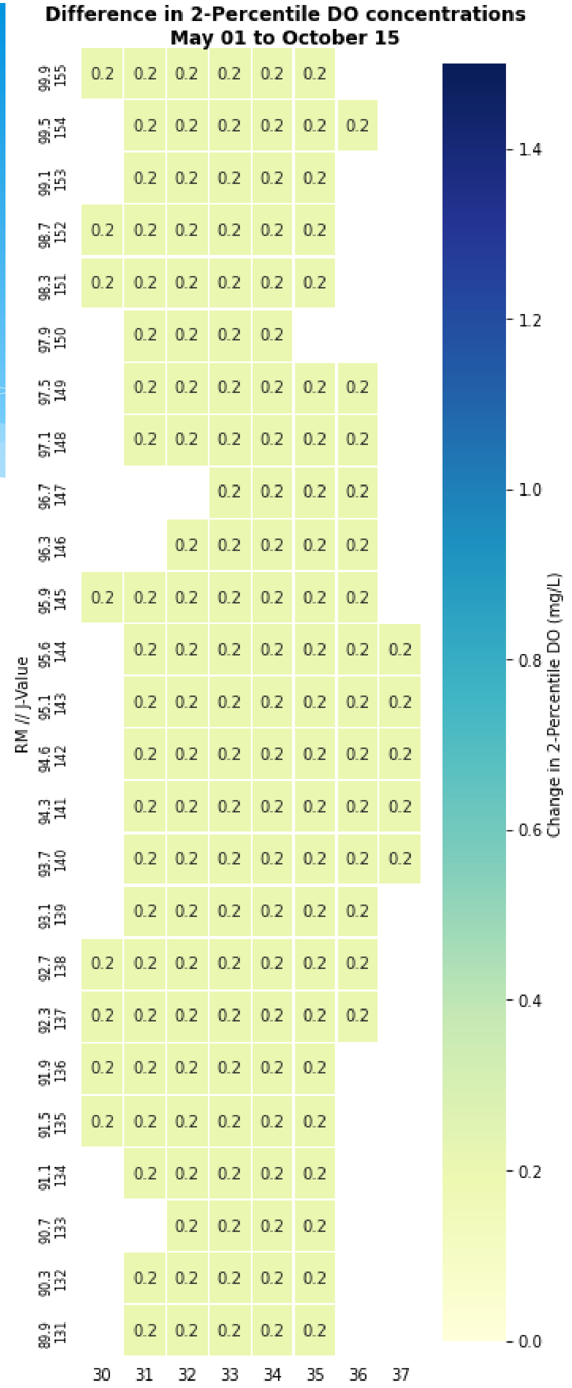
Impact of Permitted and Actual Flows (Loads)
under Baseline and Reduced Ammonia Scenarios



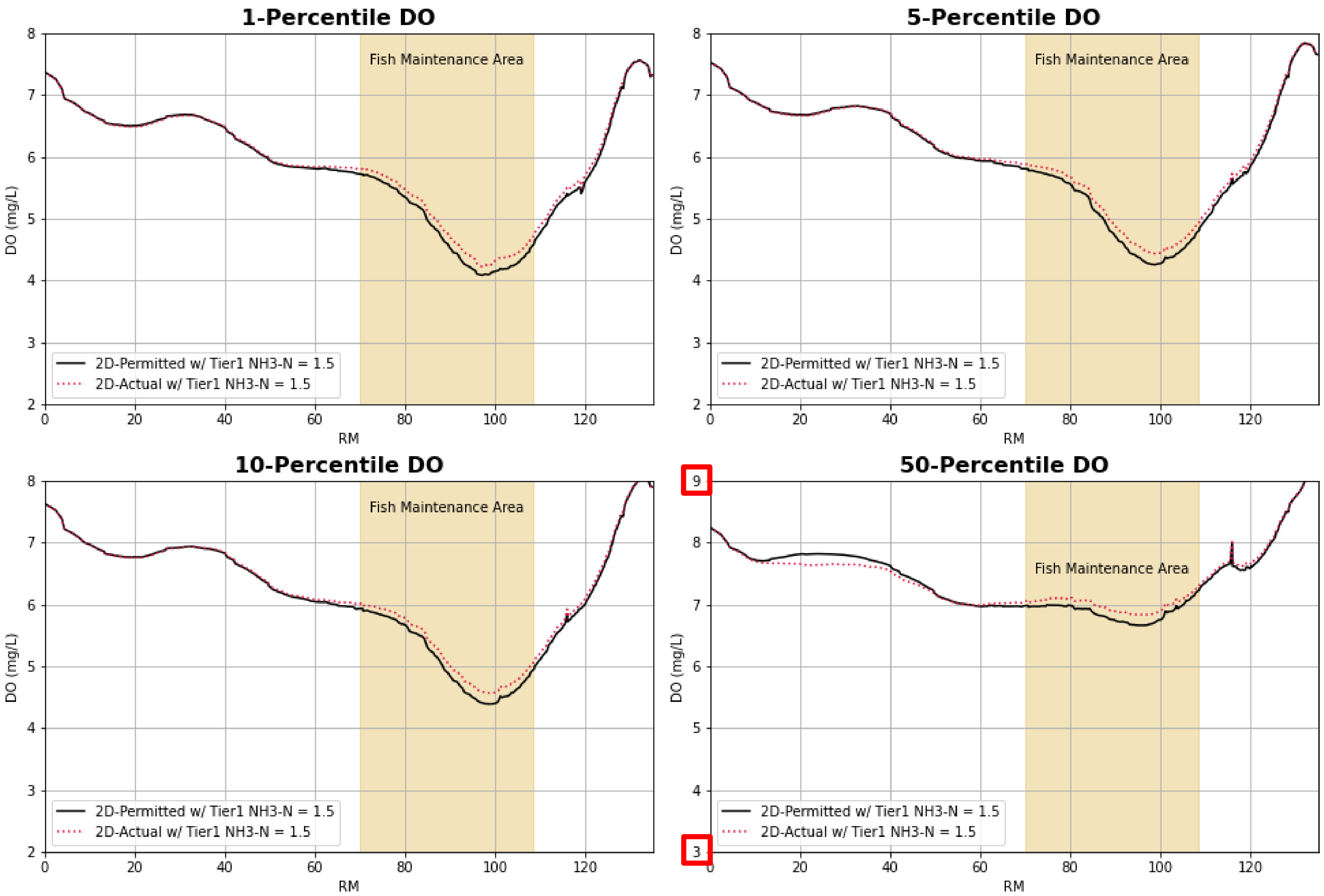
Impact of Actual and Permitted Flows

Tier 1 WWTPs set to ammonia level of 1.5 mg/L



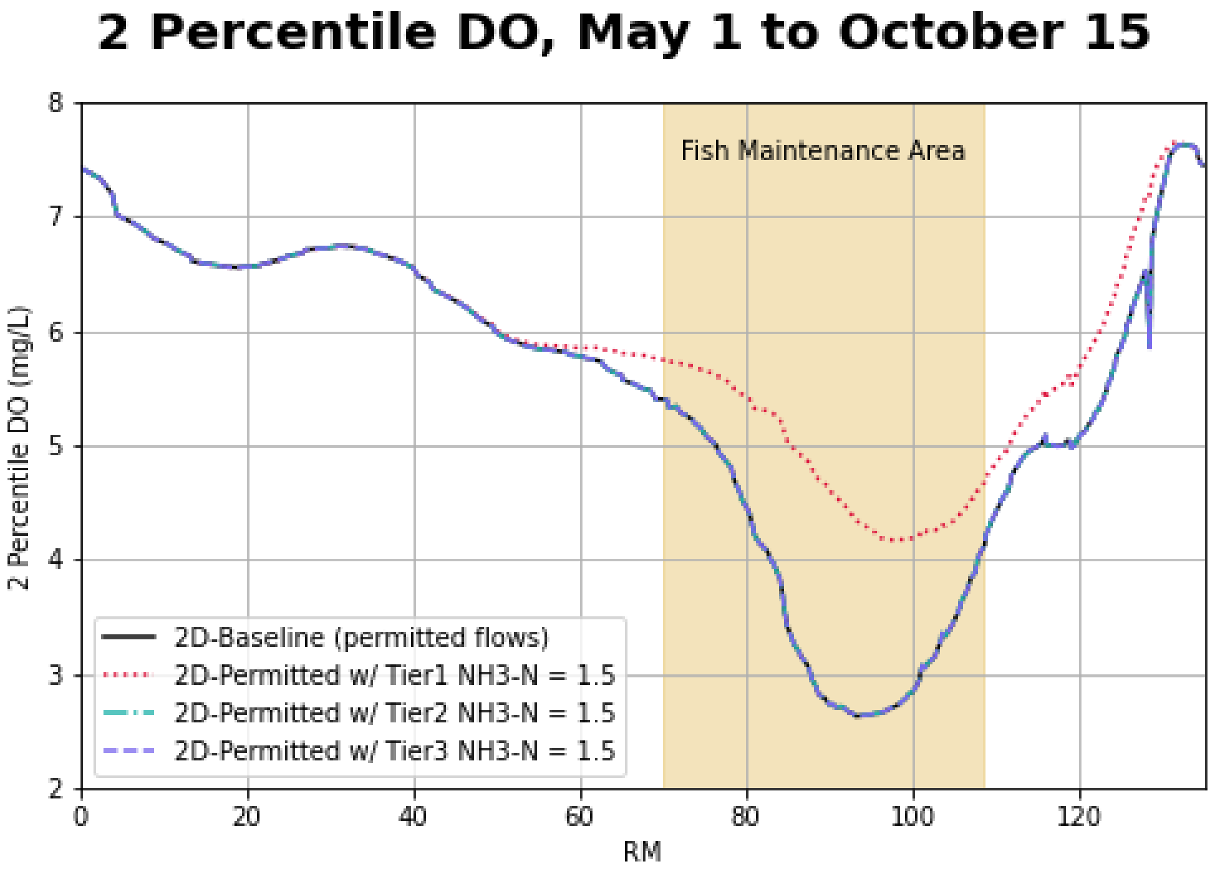


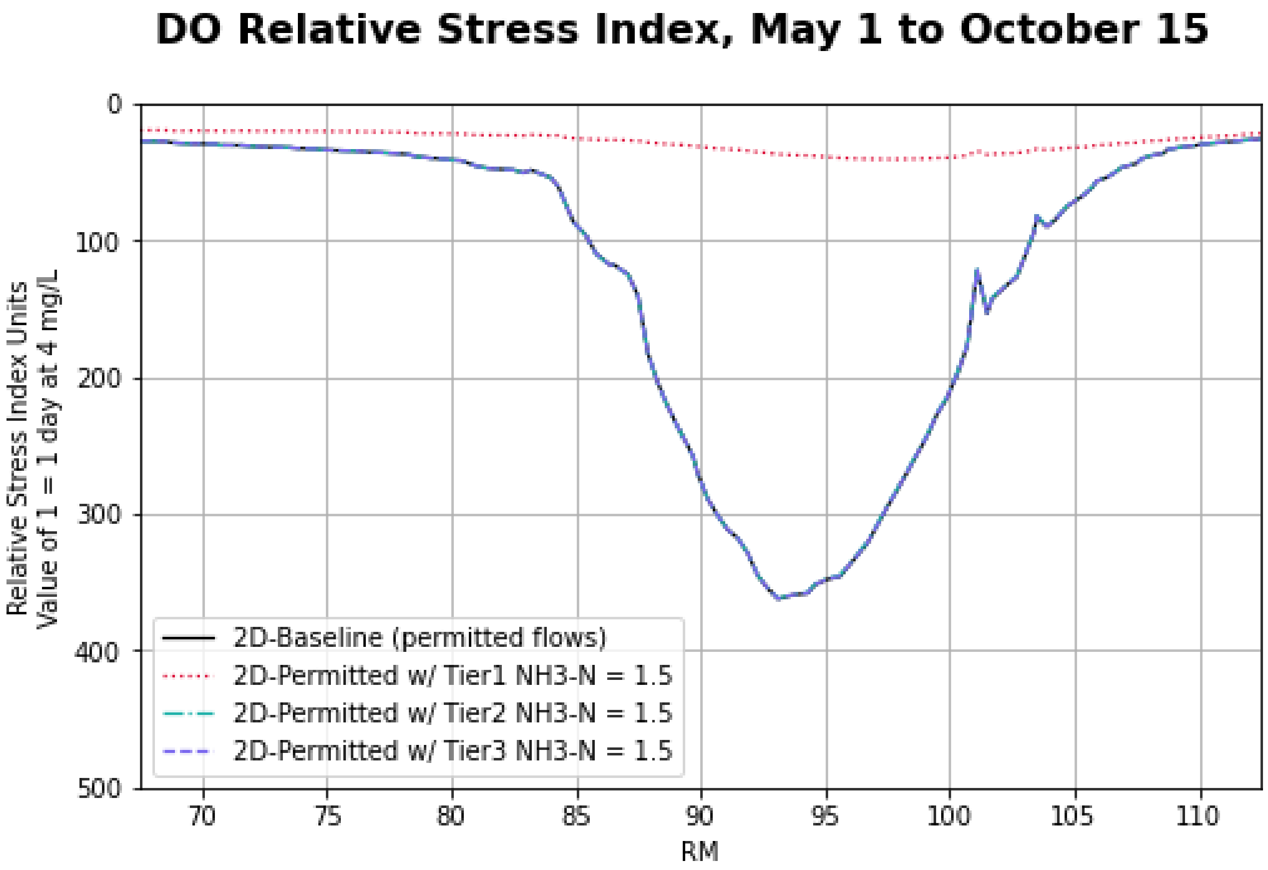
Impact of Percentile Metrics



Effluent Nitrogen Scenarios

Ammonia = 1.5 mg/L, by Tier





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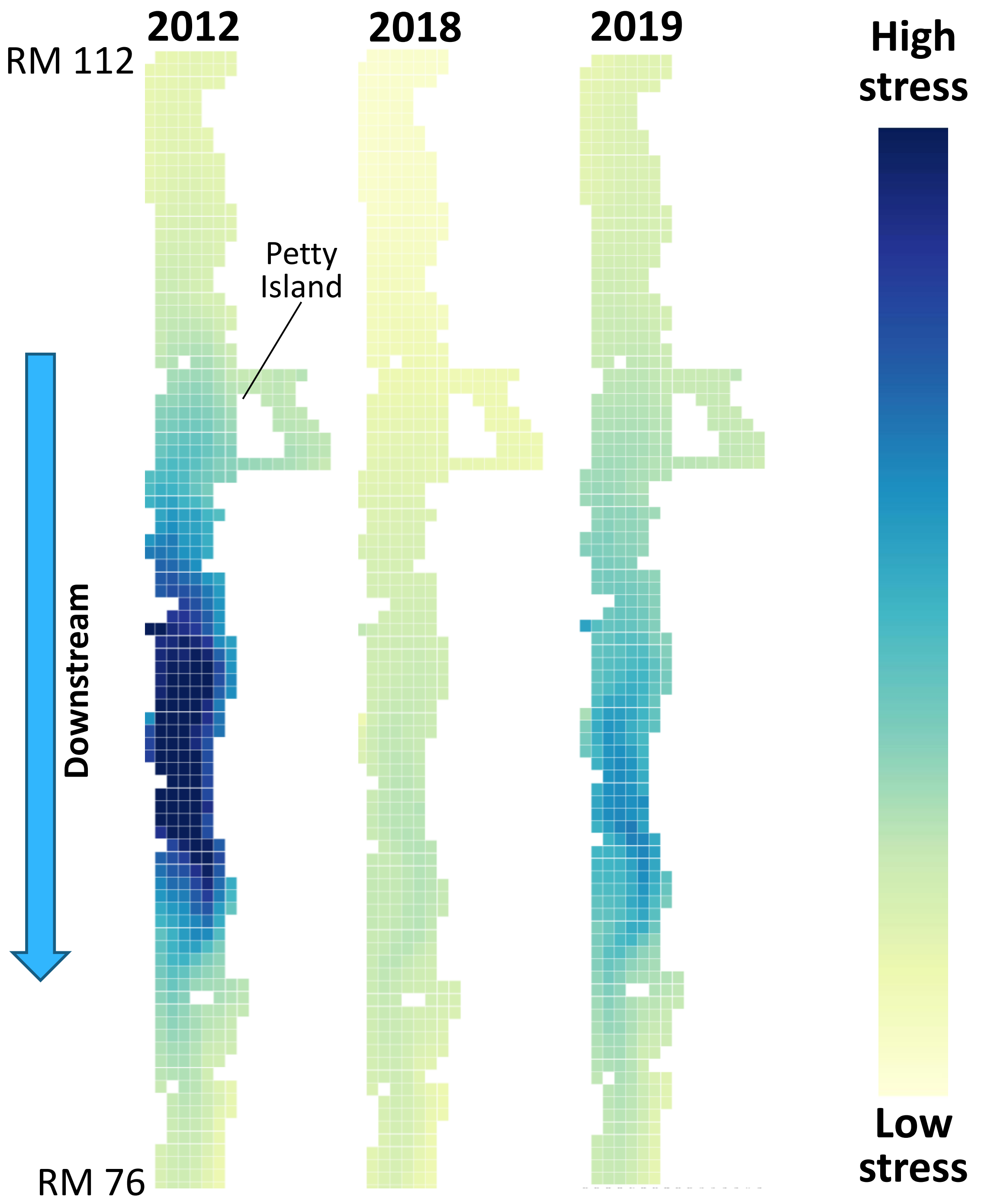
DO Relative Stress Index

1. Considers **relative stress** to aquatic life from low-DO events during different model scenarios
2. Considers **magnitude, frequency, and duration** of low-DO events, which are not captured in direct model output
3. NEW: Reflects rapidly increasing "stress" as DO decreases

   (e.g., 3.5→4 mg/L DO reduces stress more than 4.5→5 mg/L DO)



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…DOES NOT represent physical reality

1. Extension of area-under-curve calculation for DO time series
2. It cannot be measured—it compares, rather than quantifies, stress
3. The DO Relative Stress Index characterizes stress to aquatic life, but <u>it is not a model of fish mortality or metabolism</u>

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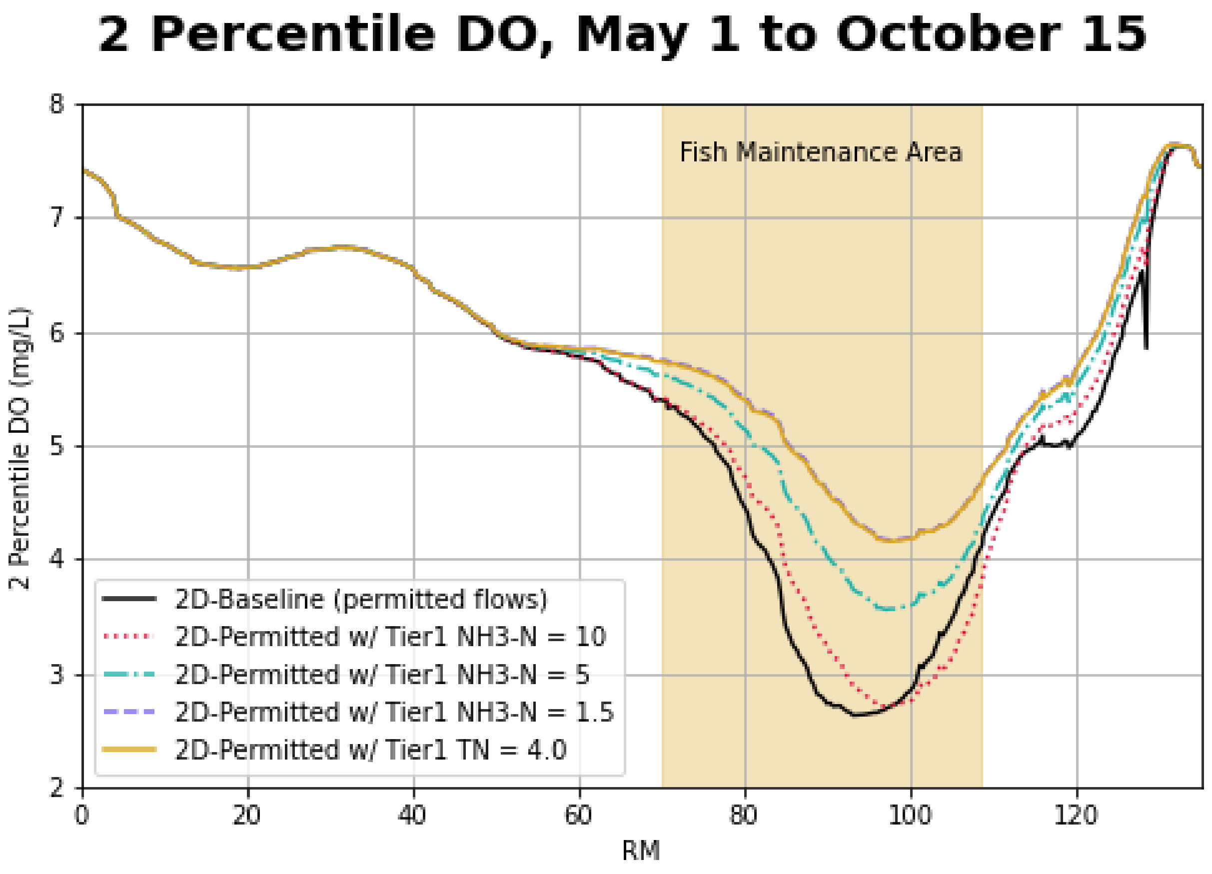
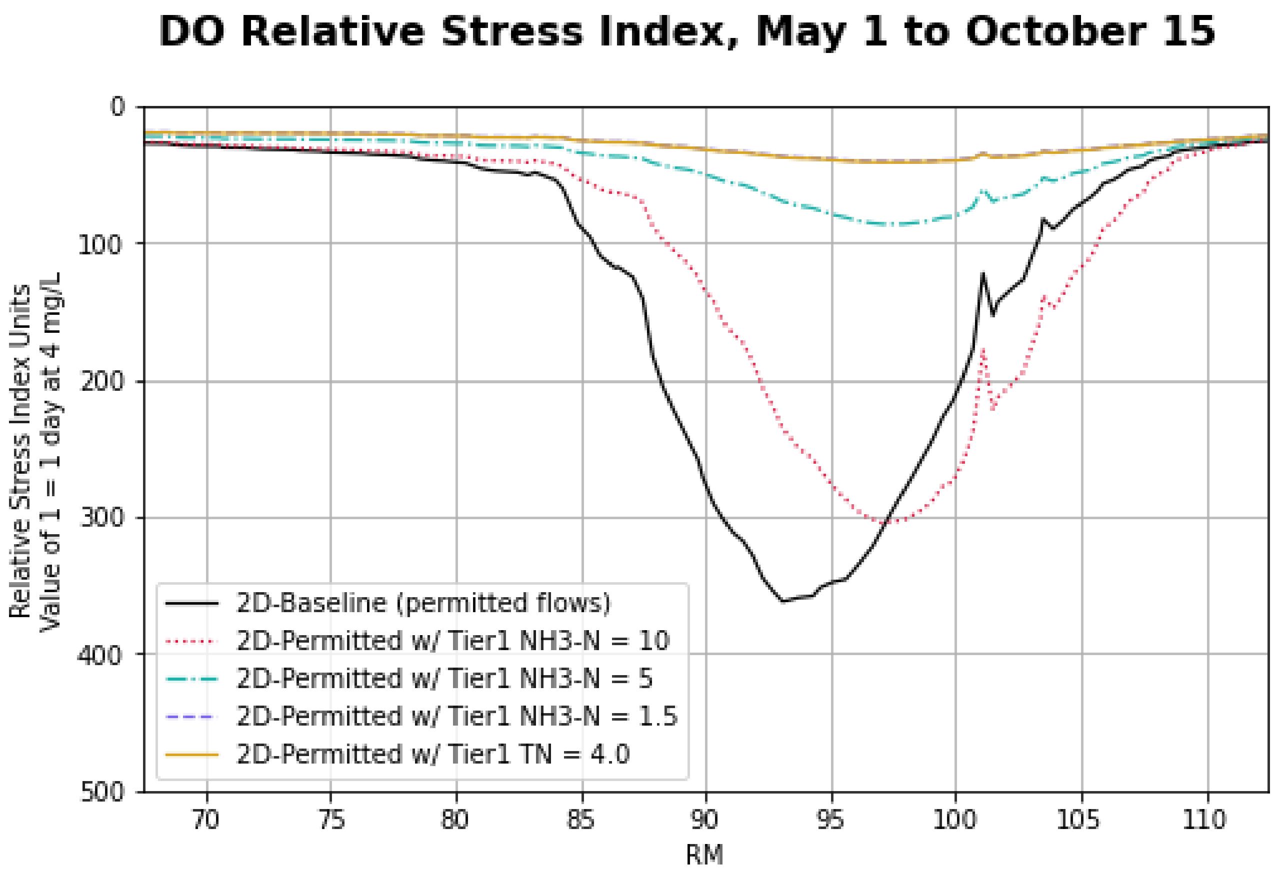
Effluent Nitrogen Scenarios (Tier 1 only)

Ammonia = 10, 5, 1.5 mg/L and TN = 4 mg/L





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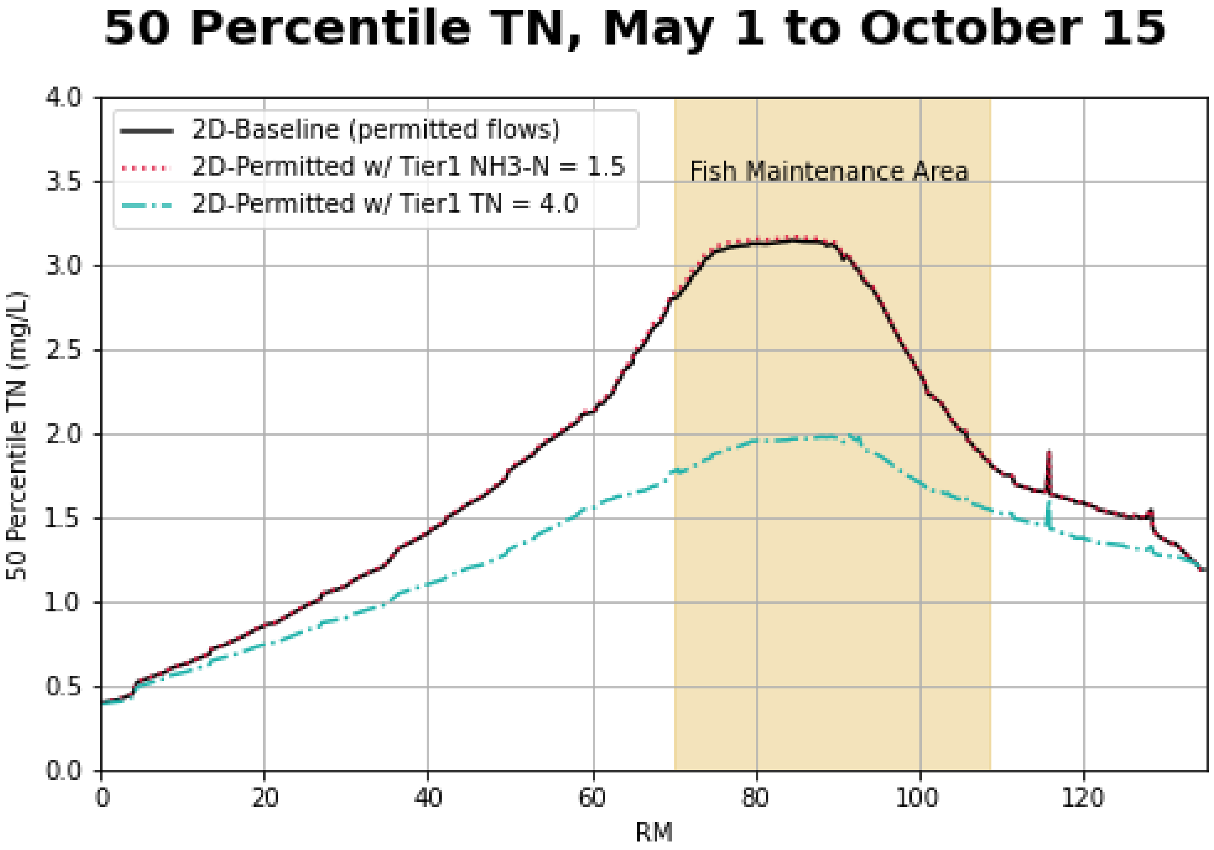
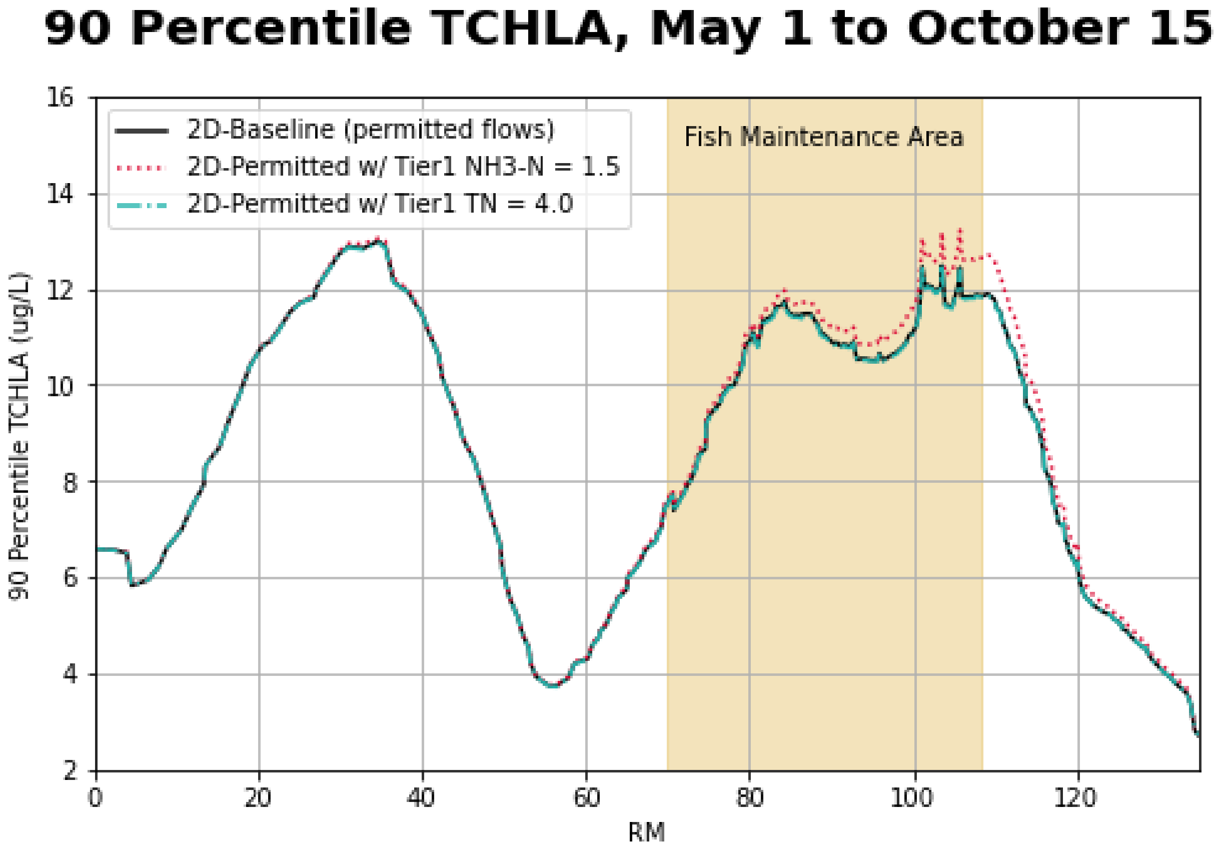
Effluent Nitrogen Scenarios (Tier 1 only)

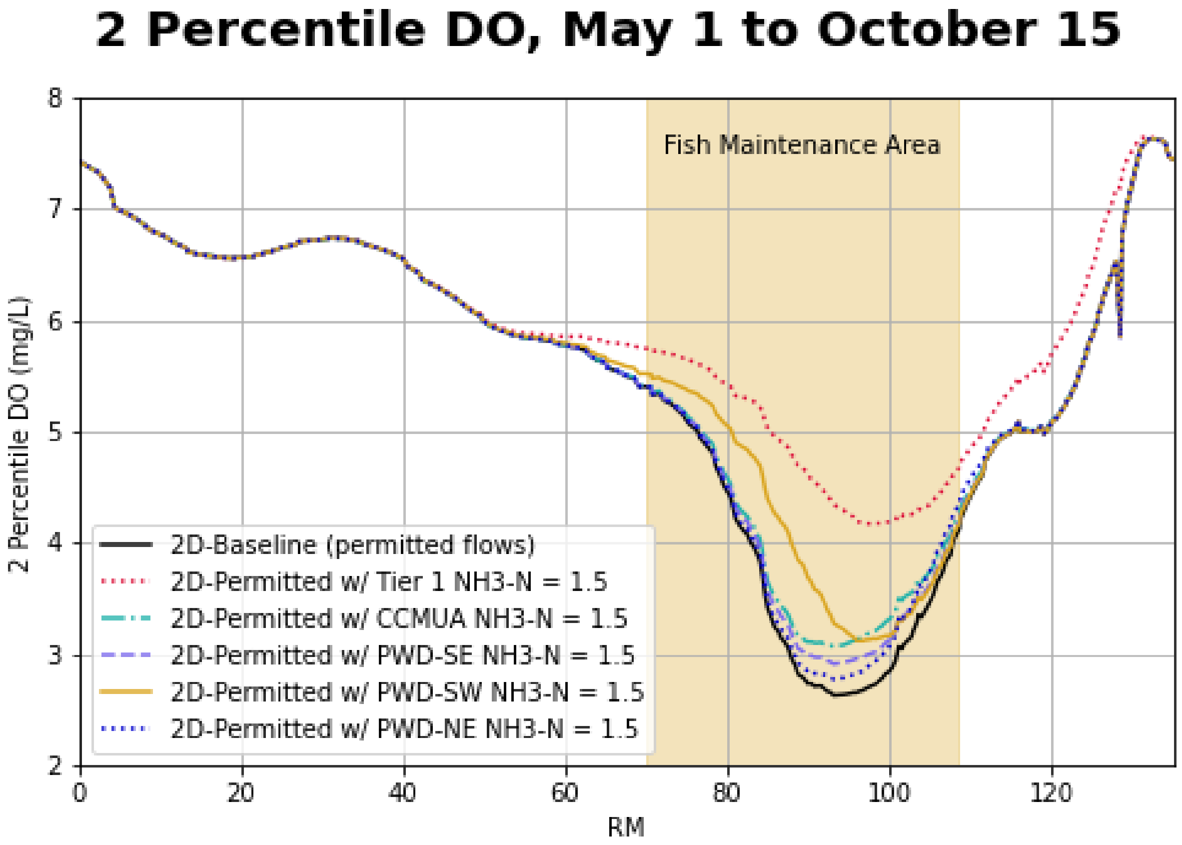
Ammonia = 1.5 mg/L and TN = 4 mg/L

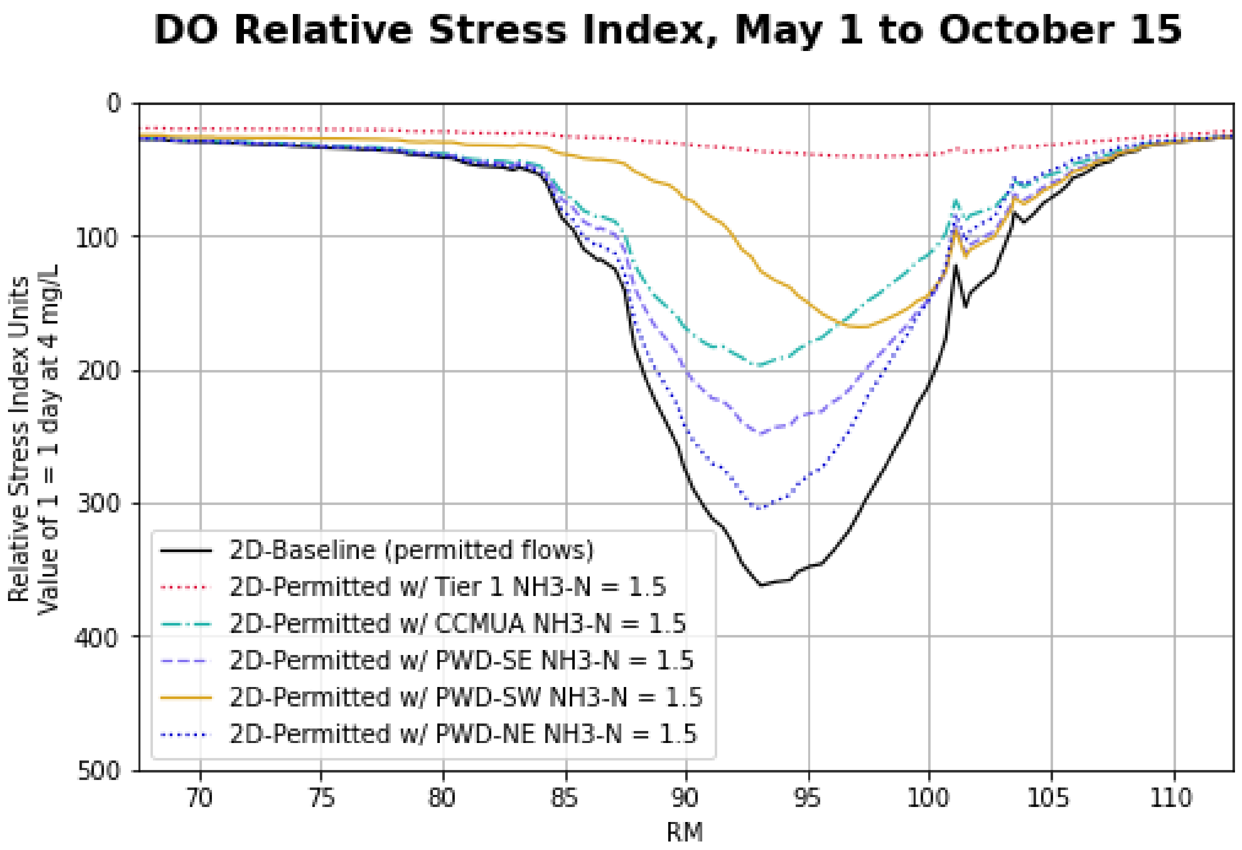




Impact of Individual Dischargers

PWD-SE, PWD-SW, PWD-NE, CCMUA





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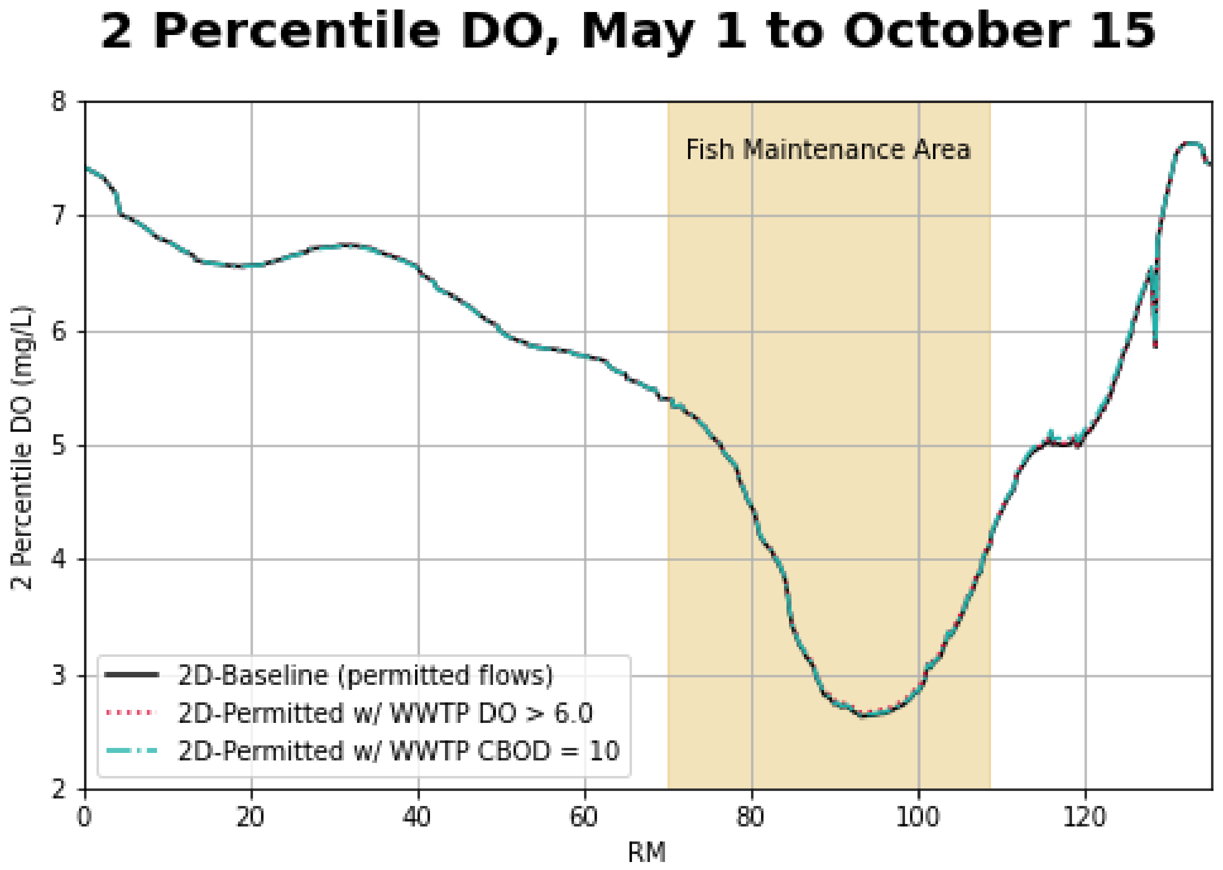
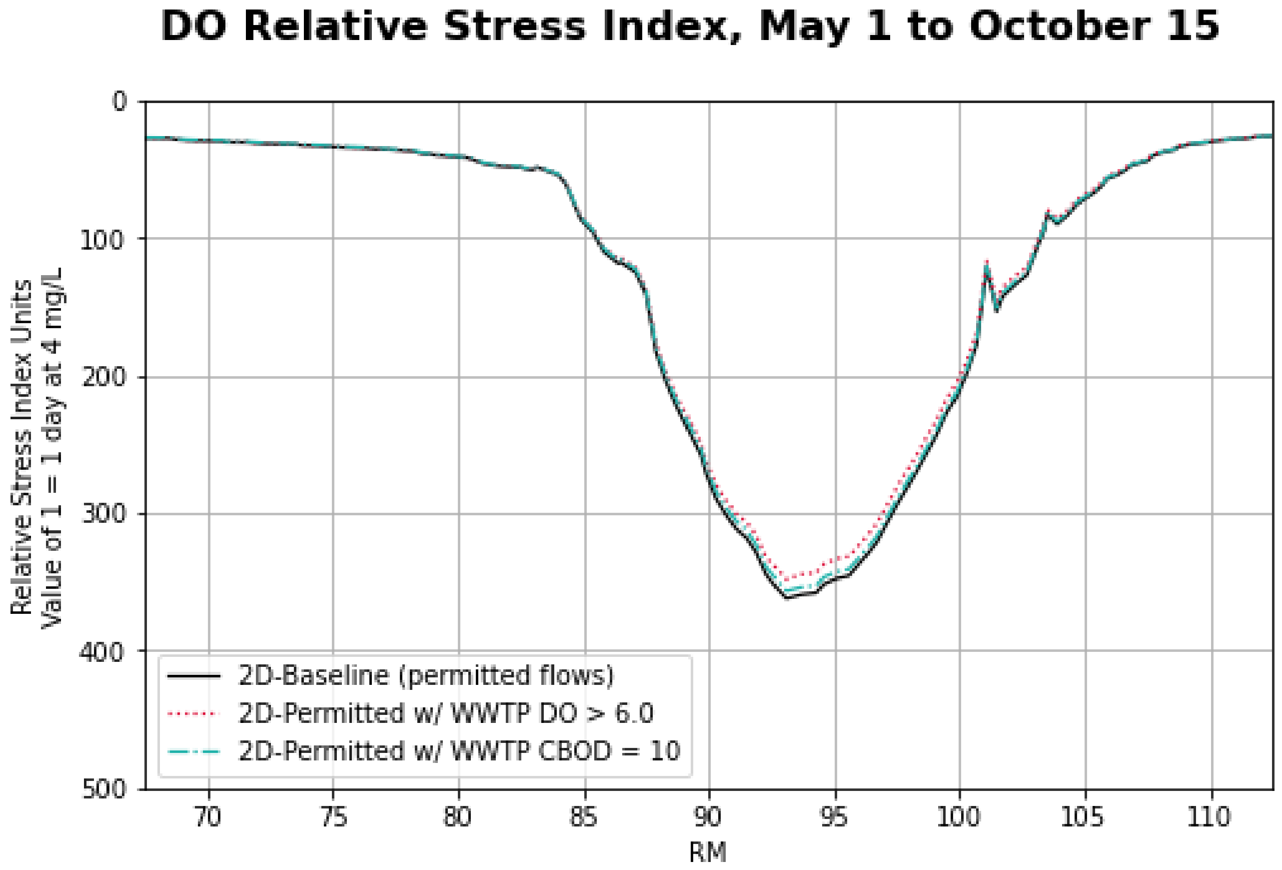
Impact of Effluent DO and CBOD

DO > 6 mg/L ; CBOD = 10 mg/L





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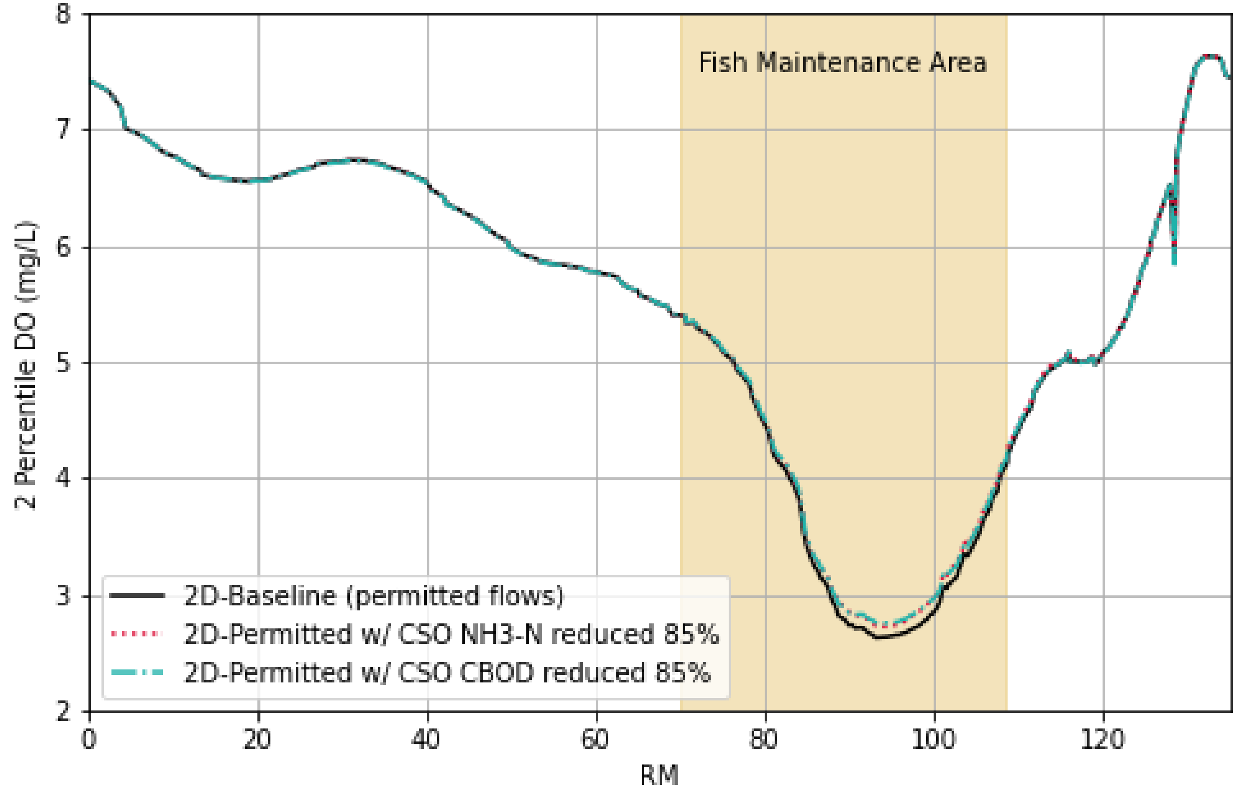
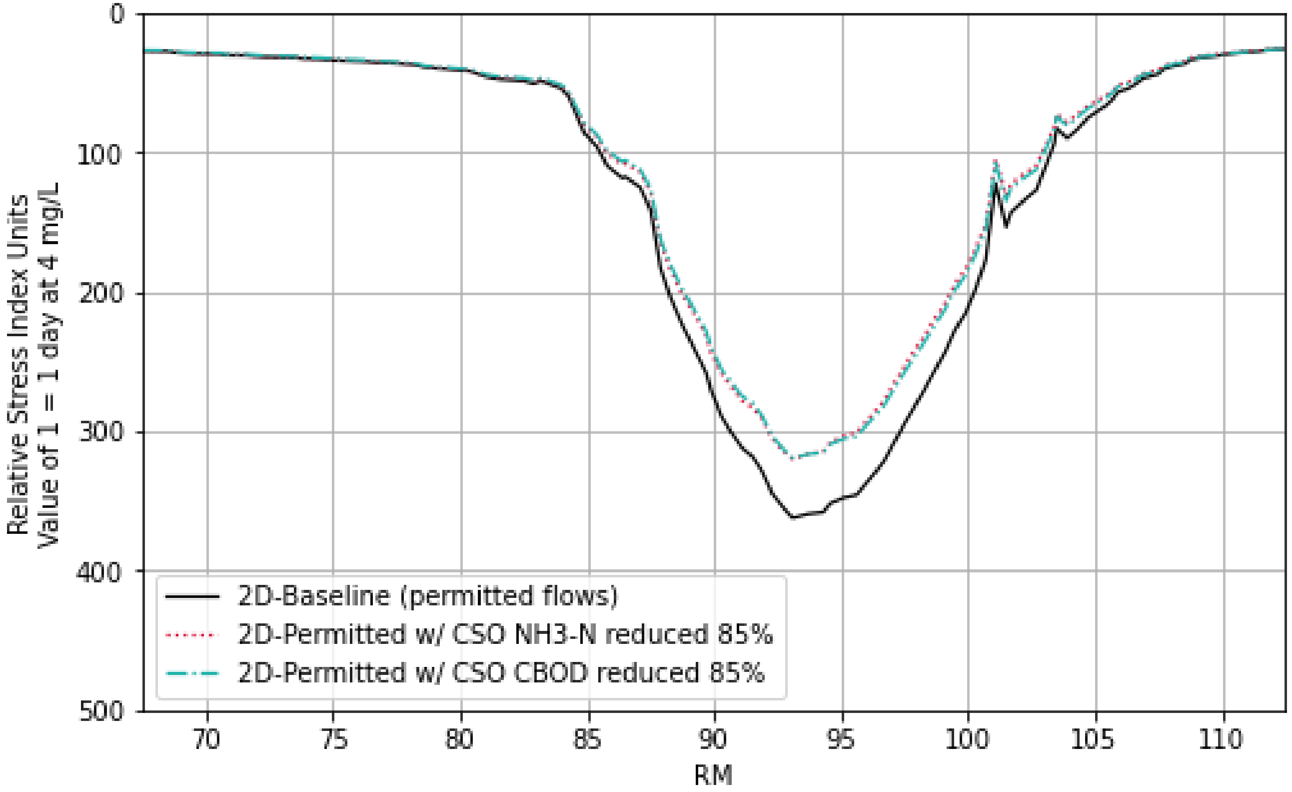
Impact of CSOs

Ammonia and CBOD decreased by 85%

2 Percentile DO, May 1 to October 15



DO Relative Stress Index, May 1 to October 15



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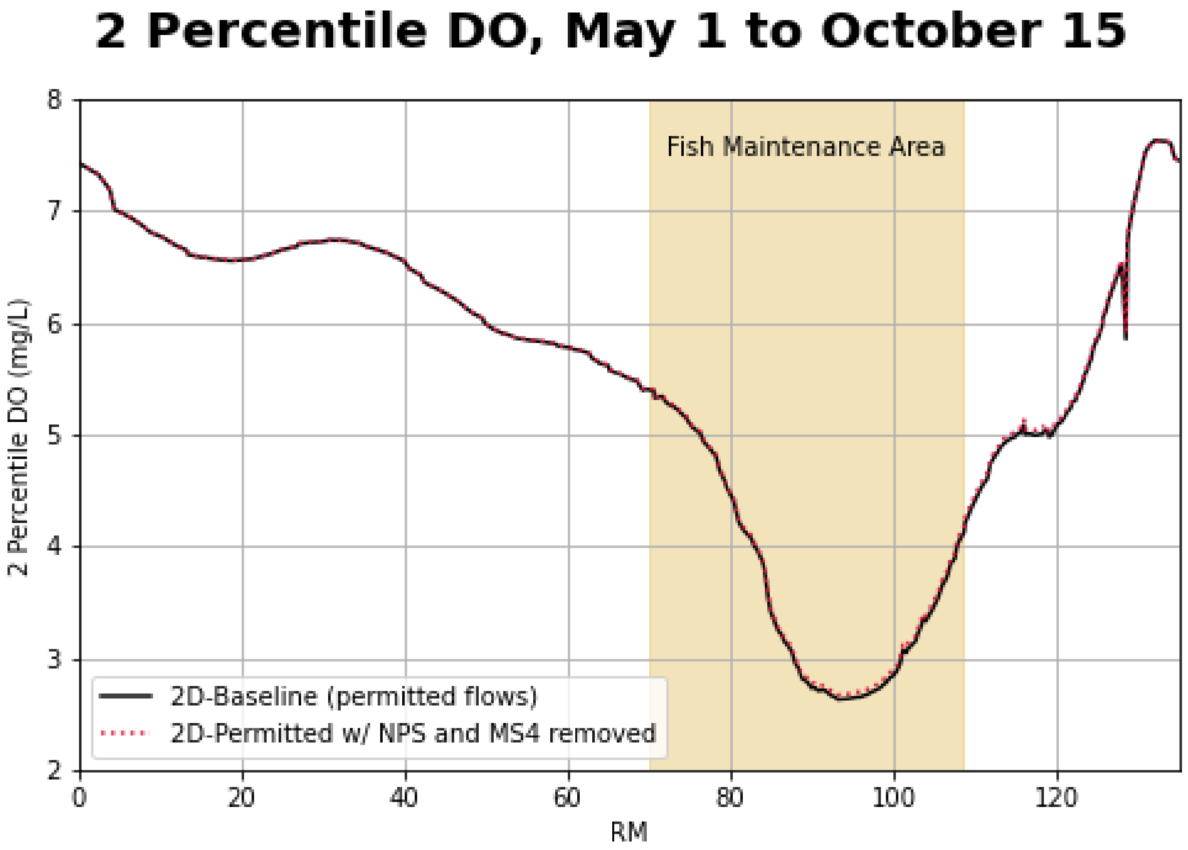
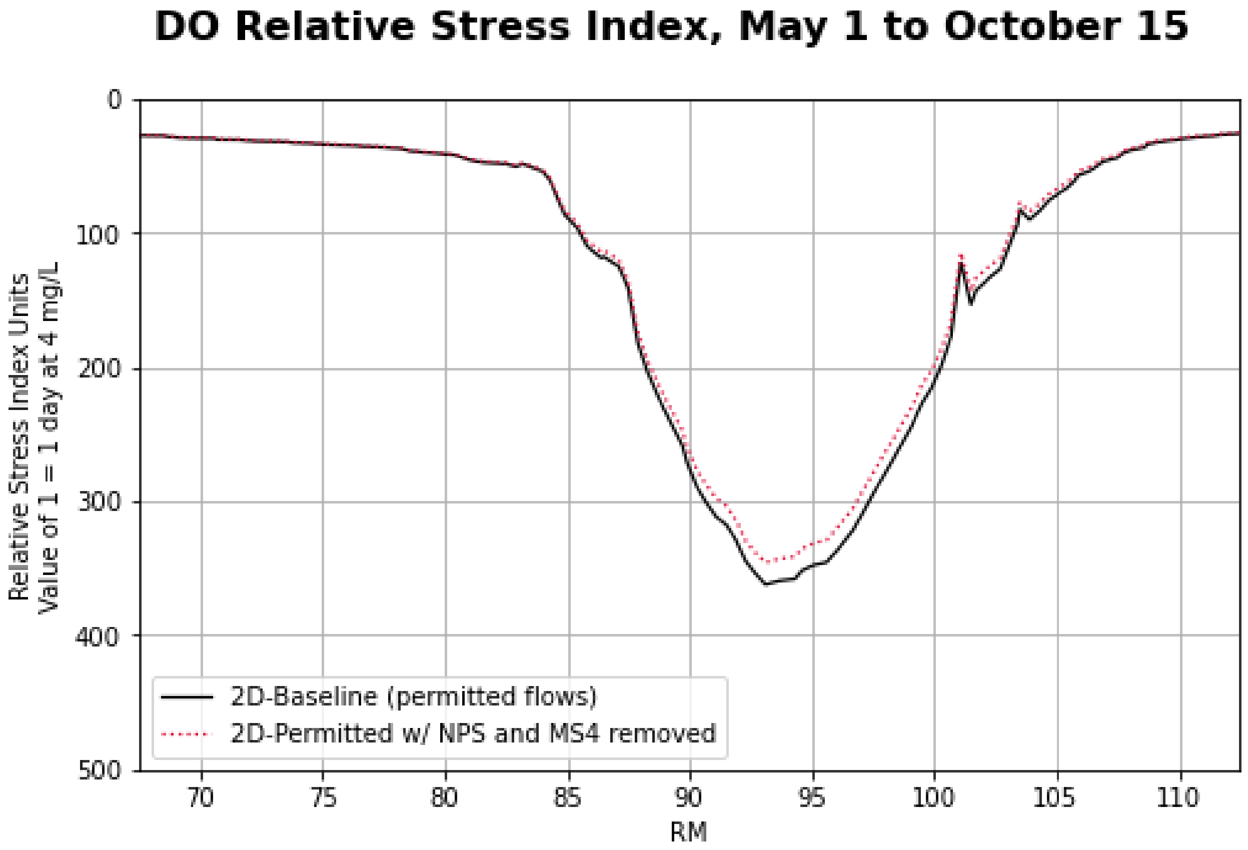
Impact of Direct Loads of NPS and MS4

reduced nitrogen and carbon set to zero





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Summary and Next Steps

Summary of Observations

- Dredging does not appear to have significantly affected dissolved oxygen
- Difference in baseline conditions based on permitted and actual effluent flows is due to the difference in loads, not the flows themselves
- Incremental DO improvements with decreased effluent ammonia
- No apparent improvement in DO can be expected from reducing TN
- Point sources drive potential DO improvements
- Some DO sag will remain

Next Steps

- Evaluate impact of tributaries
- Evaluate impact of individual dischargers using capping methodology
- Select and refine candidate scenarios
  - Run in 3D
  - Characterize costs, benefits, and affordability
- Prepare documentation for Commissioners

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Atlantic sturgeon literature review

DRBC Resolution 2017-04

6(a). Input on the **dissolved oxygen requirements of aquatic species**

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Atlantic Sturgeon / DO Literature

- The field of literature on AS/DO requirements is limited
- ~15 studies have been cited on the topic, however only 5 of these are novel studies of Atlantic sturgeon
  - Several are studies on shortnose sturgeon
  - Remaining studies are interpretations (or interpretations of interpretations) of the primary literature
- Today, we will briefly review these studies

Sturgeon/DO Primary Literature

Title	Author	Year
Tolerance of shortnose sturgeon, Acipenser brevirostrum, juveniles to different salinity and dissolved oxygen concentrations.	Jenkins et al.	1993
Effects of hypoxia and temperature on survival, growth and respiration of juvenile Atlantic sturgeon, Acipencer oxyrinchus.	Secor and Gunderson	1998
Bioenergetics modeling and assessment of suitable habitat for juvenile Atlantic and shortnose sturgeons in Chesapeake Bay.	Niklitschek	2001
Acute sensitivity of juvenile shortnose sturgeon to low dissolved oxygen concentrations.	Campbell and Goodman	2003
Dissolved oxygen, temperature and salinity effects on the ecophysiology and survival of juvenile Atlantic sturgeon in estuarine waters: I. Laboratory results.	Niklitschek and Secor	2009
Dissolved oxygen, temperature and salinity effects on the ecophysiology and survival of juvenile Atlantic sturgeon in estuarine waters: II. Model development and testing.	Niklitschek and Secor	2009
Experimental and field evidence of behavioral habitat selection by juvenile Atlantic Acipenser oxyrinchus oxyrinchus and shortnose Acipenser brevirostrum sturgeons.	Niklitschek and Secor	2010
An experimental approach to evaluate the effects of low dissolved oxygen acting singly and in binary combination with toxicants on larval Atlantic Sturgeon, Acipenser oxyrinchus oxyrinchus.	Wirgin and Chambers	2018

Title	Author	Year
Tolerance of shortnose sturgeon, Acipenser brevirostrum, juveniles to different salinity and dissolved oxygen concentrations.	Jenkins et al.	1993

- Methods
  - Cultured shortnose sturgeon juveniles, age 11-330 days from Savannah River wild stock exposed to different salinity (0-35 ppt) and dissolved oxygen concentrations (2.0-5.0 mg/liter)
  - Most DO tests conducted in fresh water
  - Tests ran for 6 hrs at non-stressful temperatures 22.5°C
- Results
  - Survival of control group (7.5 mg/L) was >95%
  - No mortality observed at 4.0, 4.5, or 5.0 mg/L
  - Survival ranged from 78-100% at 3.5 mg/L
  - Survival ranged from 62-100% at 3.0 mg/L
  - Survival ranged from 0-88% at 2.5 mg/L
  - Survival ranged from 8-78% at 2.0 mg/L
  - Older fish had higher survival across all runs
- Author Discussion
  - Older fish could tolerate hypoxia for short periods
  - The dissolved oxygen levels tolerated in these short tests should be considered absolute minimum tolerance levels
- DRBC Interpretation
  - ≥4.0 mg/L for 6 hrs or less is protective of YOY shortnose sturgeon mortality
  - Hypoxia driven mortality at levels below 4.0 mg/L is dependent on sturgeon age

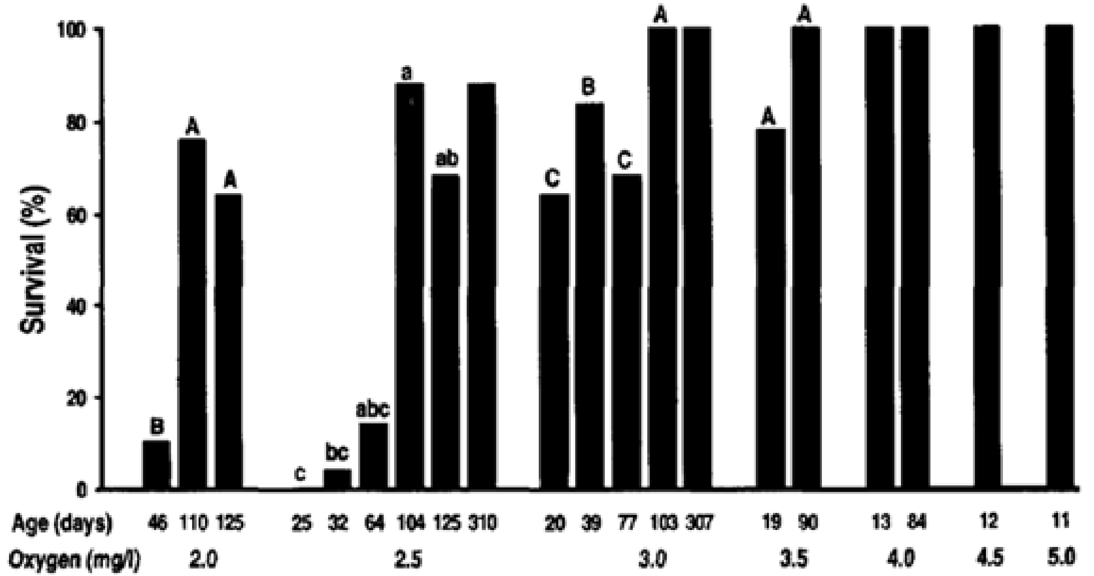

Figure 2. Survival of various aged shortnose sturgeon exposed to different oxygen concentrations. Data with same letter (anova=uppercase; Kruskal-Wallis=lowercase) within a particular test concentration are not significantly different.

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Title	Author	Year
Effects of hypoxia and temperature on survival, growth and respiration of juvenile Atlantic sturgeon, Acipencer oxyrinchus.	Secor and Gunderson	1998

Methods

- Fish were spawned from Hudson River wild stock
- Juvenile AS (>10 cm TL) tested for growth, survival, and respiration
- Tests ran for 10 days under different combinations of surface access, temperature (19°C vs 26°C), and DO (~3 mg/L vs ~7 mg/L)
- Salinity varied from 1.5-3 ppt

Results

- Deaths were observed only in ~3 mg/L treatments
- Survival significantly higher at low temps (78%) than high temps (8%) during ~3 mg/L treatments
- Timing of mortality was variable (day 1 - day 10)
- Growth and respiration affected by DO

Author Discussion

- Juvenile Atlantic sturgeon were vulnerable to high temp and low DO

DRBC Interpretation

- 3.3 mg/L at high temps is lethal to sturgeon (presumed on the timescale of multiple hours to days)
- Non-lethal effects observed at 3.3 mg/L

Experiment	DO level	Rep.	Experimental day 1	2	3	4	5	6	7	8	9	10	Survival (%)
26°C unsealed 1	Low	1			6	1	1						0
		2			2		4					2	0
		3		4			1	2	1				0
		4				1		1		1	1		50
26°C unsealed 2	High	1											100
		2											100
		3											100
		4											100
26°C sealed	Low	1	8										0
		2	7	1									0
	High	1											100
		2											100
19°C unsealed	Low	1			1		1						75
		2			1			1					75
	High	1											100
		2											100
19°C sealed	Low	1							1				88
		2						1	1				75
	High	1											100
		2											100

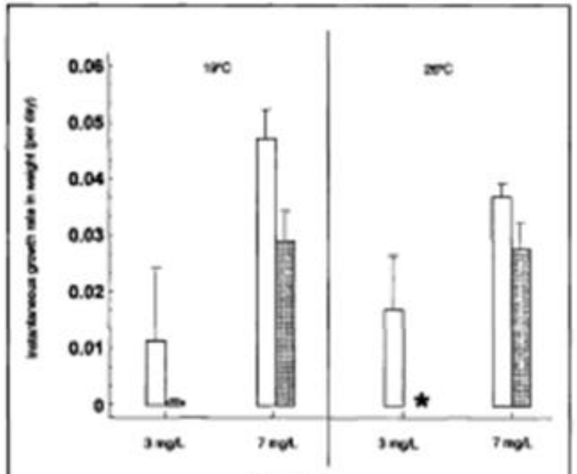

Figure 2

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Title	Author	Year
Acute sensitivity of juvenile shortnose sturgeon to low dissolved oxygen concentrations.	Campbell and Goodman	2003

- Methods
  - Developed 24-hour LC50s for shortnose sturgeon
- Results
  - LC50 value after 24 h for 77-d-old fish and 2% salinity at 25°C was 2.7 mg/L
  - LC50 value after 24 h for 104-d-old fish and 4% salinity at 22°C was 2.2 mg/L
  - LC50 values after 24-h, 48-h, and 72-h for 134-d-old fish tested at 4.5% salinity and 26°C was 2.2 mg/L
  - LC50 value after 24 h for 100-d-old fish and 2% salinity at 30°C was 3.1 mg/L
- Author Discussion
  - Shortnose sturgeon are sensitive to low DO
- DRBC Interpretation
  - LC50 for shortnose sturgeon at stressful temps for 24 hrs is 3.1 mg/L
  - EPA developed a CMC of 4.3 mg/L from this study

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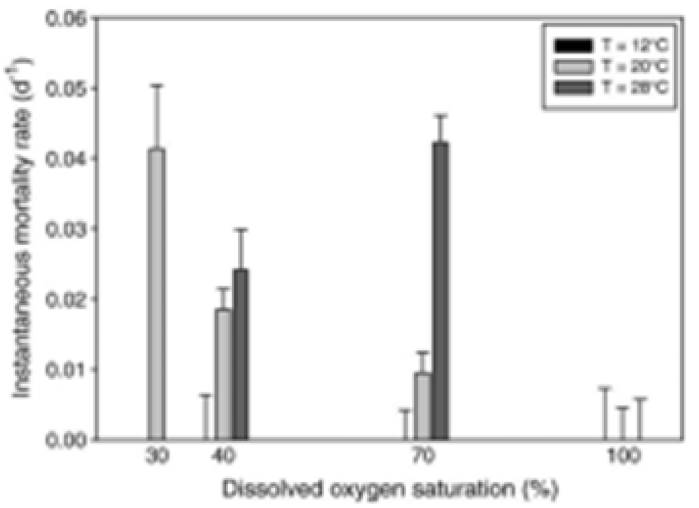
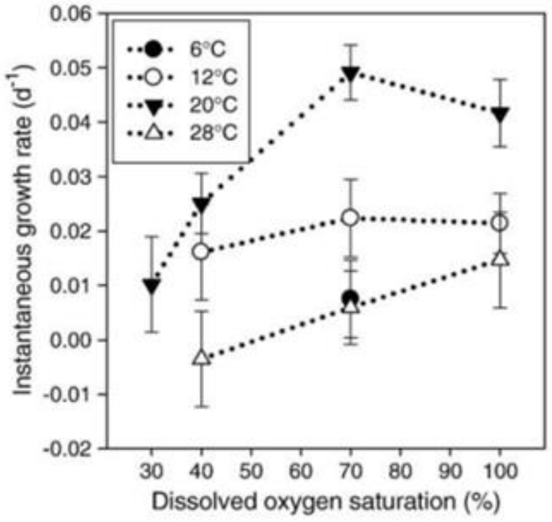
Title	Author	Year
Dissolved oxygen, temperature and salinity effects on the ecophysiology and survival of juvenile Atlantic sturgeon in estuarine waters: I. Laboratory results.	Niklitschek and Secor	2009



- Methods
  - Hatchery-produced Atlantic sturgeon juveniles, offspring from Hudson River parents
  - Measured growth, consumption, metabolism, egestion and survival in microcosms
  - Effects were evaluated for temp (12, 20 and 28°C), DO (40, 70, 100% DO sat), and salinity (1, 8 , 15, 22, 29)
  - Survival was measured over 21 d
- Results
  - YOY Atlantic sturgeon growth and mortality was significantly affected by dissolved oxygen, temperature and salinity
  - Mortality results difficult to interpret
  - Non-lethal effects show that the DO saturation levels corresponding to highest rates vary with temperature
- Author Discussion
  - "For illustration purposes, if optimal growth or survival rates were used as criteria to set a hypoxia threshold for juvenile Atlantic sturgeon, that value would rise from 40 to 70% DOSAT if temperature increased from 12 to 20 °C. At salinity 1 these values would correspond to concentrations of 4.3 and 6.3 mg l−1, respectively."
- DRBC Interpretation
  - At 20°C, growth and survival rates are higher at 70% DO SAT vs 30% or 40% DO SAT.



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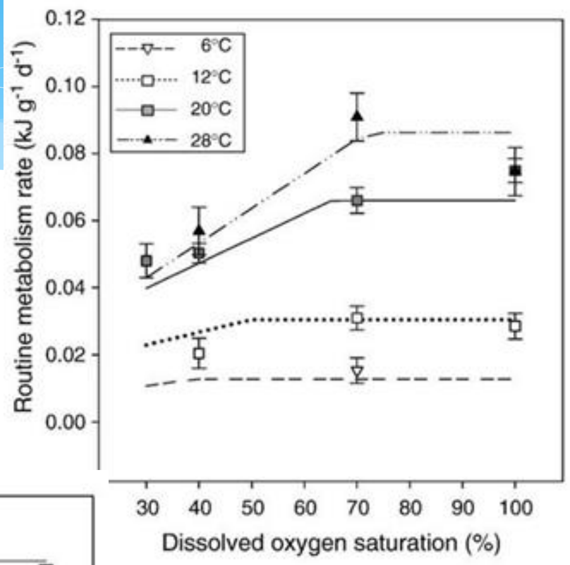
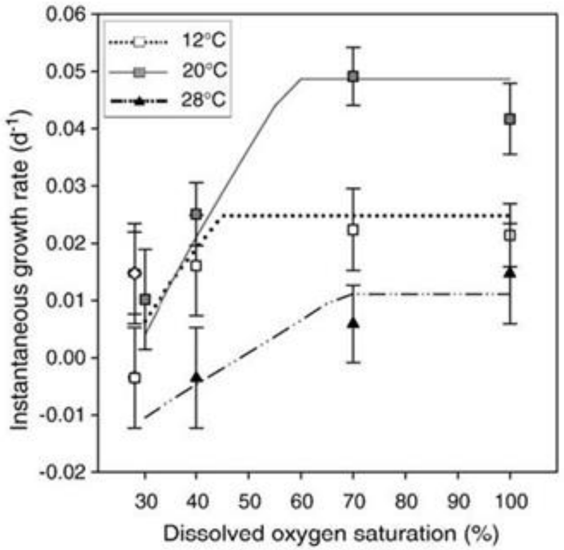
Title	Author	Year
Dissolved oxygen, temperature and salinity effects on the ecophysiology and survival of juvenile Atlantic sturgeon in estuarine waters: II. Model development and testing.	Niklitschek and Secor	2009

- Methods
  - Developed bioenergetic model incorporating DO and salinity effects from previous laboratory study
- Results
  - DO SAT associated with optimal growth and metabolism was often less than 70%
- Author Discussion
  - Authors did not discuss effects of DO in the discussion
- DRBC Interpretation
  - Optimal DO SAT at 20 degrees C for juvenile Atlantic sturgeon appears to be in the 60-65% range based on the bioenergetics model





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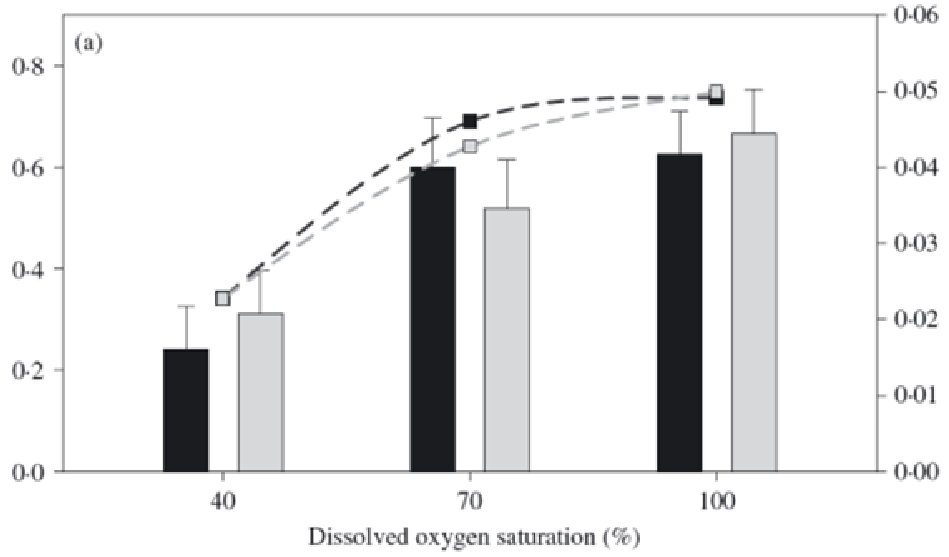
Title	Author	Year
Experimental and field evidence of behavioral habitat selection by juvenile Atlantic Acipenser oxyrinchus oxyrinchus and shortnose Acipenser brevirostrum sturgeons.	Niklitschek and Secor	2010

- Methods
  - Hatchery produced shortnose (Savannah River) and Atlantic (Hudson)
  - Series of behavior experiments
  - Effects were evaluated for temp (12, 20 and 28°C), DO (40, 70,100% DO sat), and salinity (1, 8 , 15)
  - DO test were conducted at 20°C and salinity of 8.
- Results
  - No difference in behavioral results between the two species
  - Clear avoidance of the lowest DO (40%), but no difference between higher DO (70vs100%)
- Author Discussion
  - "Contrasting these results to those presented here gives additional support to the idea that acipenserids may be particularly sensitive to hypoxia, showing avoidance and physiological reactions to oxygen saturation levels <70%“
- DRBC Interpretation
  - Non-lethal effects seen at 40% DOSAT and 20°C and salinity of 8.



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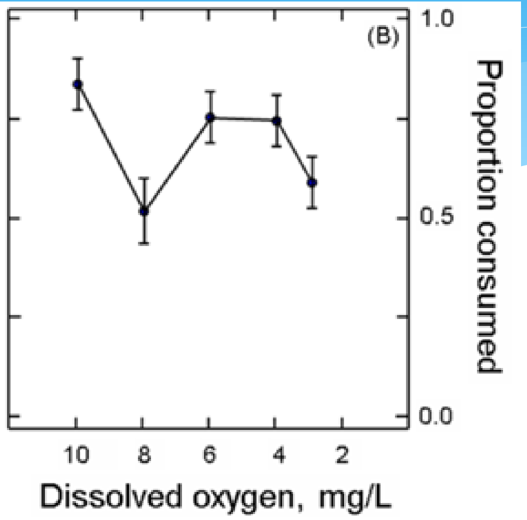
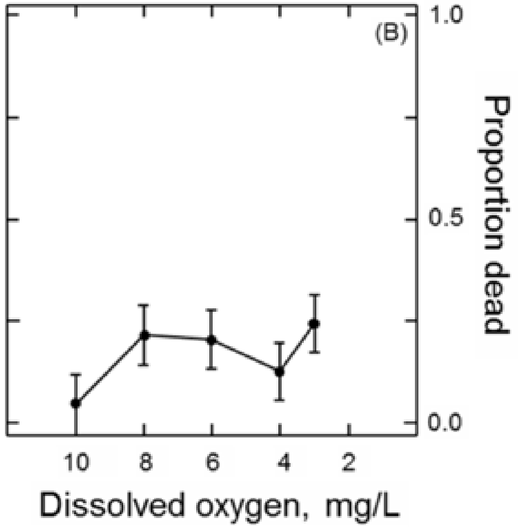
Title	Author	Year
An experimental approach to evaluate the effects of low dissolved oxygen acting singly and in binary combination with toxicants on larval Atlantic Sturgeon, Acipenser oxyrinchus oxyrinchus	Wirgin and Chambers	2018



- Methods
  - Hatchery spawned Atlantic sturgeon from Canada and South Carolina
  - Experimentally evaluated to effects of DO and toxicants
  - Evaluated DO doses of 3,4,6,7,8,10 mg/L on mortality, prey consumption, and activity
  - 21-hr trial at non-stressful temps
- Results
  - Varying results between the sources of sturgeon (SC sturgeon were younger which could have made them more susceptible to the effects)
  - Generally, DO effects were not significant on mortality (one grouping of SC sturgeon showed significant effect of DO)
  - DO often affected prey consumption
- Author Discussion
  - Limited discussion of DO effects
  - “These results suggest that prey consumption by larval sturgeon of Atlantic sturgeon at low DO levels could be affected in situ”
- DRBC Interpretation
  - Non-lethal effects seen at lower DO concentrations



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Sturgeon/ DO Secondary Literature

Title	Author	Year	Takeaways related to DO thresholds
Hypoxia and Sturgeons: report to the Chesapeake Bay Program Dissolved Oxygen Criteria Team ——————————————— Sensitivity of Sturgeons To Environmental Hypoxia: A Review of Physiological and Ecological Evidence	Secor and Niklitschek	2001	• Sturgeon are sensitive to hypoxia in terms of metabolic and behavioral response • YOY sturgeon experience lost production below 60% DO SAT (4.3-4.7 mg/L @ 22-27°C) • Lethal effects observed below 3.3 mg/L
Ambient Water Quality Criteria for Dissolved Oxygen, Water Clarity and Chlorophyll a for the Chesapeake Bay and Its Tidal Tributaries	EPA	2003, 2017	• 3.2 mg/L protective of mortality as non-stressful temps • 4.3 mg/L protective of mortality at stressful temps • 5 mg/L deemed protective against adverse growth effects
Atlantic Coast Diadromous Fish Habitat: A Review of Utilization, Threats, Recommendations for Conservation, and Research Needs	ASFMC	2009	• Dissolved oxygen > 5 mg/L optimal for juvenile Atlantic sturgeon

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Sturgeon/ DO Secondary Literature

Title	Author	Year	Takeaways related to DO thresholds
Potential Impacts of Dissolved Oxygen, Salinity and Flow on the Successful Recruitment of Atlantic Sturgeon in the Delaware River	TNC	2016	• > 6 mg/L optimal • 5 mg/L suitable • 4 mg/L impaired • < 3.3 mg/L lethal
Designation of Critical Habitat for Endangered New York Bight, Chesapeake Bay, Carolina and South Atlantic Distinct Population Segments of Atlantic Sturgeon and Threatened Gulf of Maine Distinct Population Segment of Atlantic Sturgeon	NMFS	2017	• Habitat with DO 6 mg/L likely supports juvenile rearing, < 5.0 mg/L for longer than 30 days is less likely to support rearing when temperature > 26°C, 4.3 mg/L is needed to protect survival and growth. • This purpose of this document was to characterize habitat preferences.
A Review of Dissolved Oxygen Requirements for Key Sensitive Species in the Delaware Estuary	ANSDU	2018	• Identified relevant research (e.g., Niklitschek and Secor) relating lethal and non-lethal effects to DO and reported several values • The purpose of this report was to assemble relevant literature

Basis for fish suitability determinations

DRBC Resolution 2017-04

6(a). Input on the **dissolved oxygen requirements of aquatic species**

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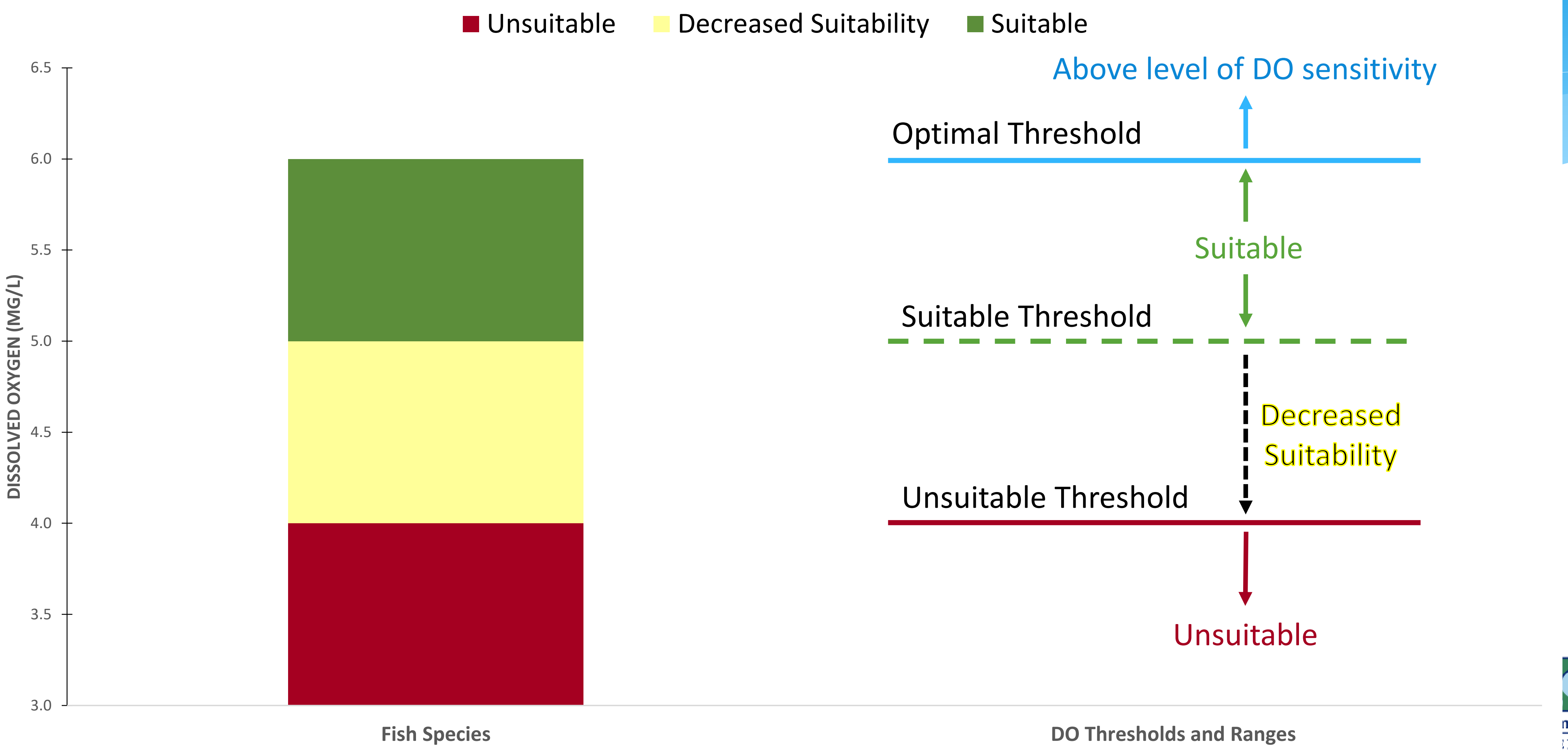
Conceptual Model Relating Dissolved Oxygen to Use



Criteria for aquatic life use suitability are not generally based on 100% protection

The Criterion Maximum Concentration is intended to protect 95 percent of a group of diverse genera, unless a commercially or recreationally important species is very sensitive.

DOCUMENT: Guidelines for Deriving Numerical National Water Quality Criteria for the Protection Of Aquatic Organisms and Their Uses

AUTHOR: EPA

YEAR: 1985

NOTES: In our circumstance, we are looking at minimum DO criteria to protect all eight DO-sensitive species

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Suitability criteria are often based on agency judgement

(“meta-analysis” or “weight-of-evidence”)

To determine a criterion value that would also protect sturgeon from nonlethal effects, bioenergetic and behavioral responses were considered which had been derived from laboratory studies conducted on juvenile Atlantic and shortnose sturgeon (Niklitschek 2001; Secor and Niklitschek 2001). Growth was substantially reduced at 40 percent oxygen saturation compared to normal oxygen saturation conditions (greater than or equal to 70 percent saturation) for both species at temperatures of 20°C and 27°C. Metabolic and feeding rates declined at oxygen levels below 60 percent oxygen saturation at 20°C and 27°C. In behavior studies, juveniles of both sturgeon species actively selected 70 percent or 100 percent oxygen saturation levels over 40 percent oxygen saturation levels. Based on these findings, a 60 percent saturation level was deemed protective for sturgeon. This corresponds to 5 mg liter^{-1} at 25°C. Therefore, a 5 mg liter^{-1} Chesapeake Bay criterion protecting against adverse growth effects would protect sturgeon growth as well.

DOCUMENT: Ambient Water Quality Criteria for Dissolved Oxygen, Water Clarity and Chlorophyll a for the Chesapeake Bay and Its Tidal Tributaries

AUTHOR: EPA

YEAR: 2003

NOTES: While this document is nearly 20 years old, the research cited here remains relevant. Niklitschek 2001 is Edwin Niklitschek’s doctoral dissertation from his time in Dave Secor’s lab. Niklitschek and Secor 2009 (the paper from which the 6.3 value was derived) was published from this dissertation research.

Table II-1. Chesapeake Bay dissolved oxygen water quality criteria.

Designated Use	Criteria Concentration/Duration	Protection Provided	Temporal Application
Migratory fish spawning and nursery use	7-day mean ≥ 6 mg/L (tidal habitats with 0-0.5 salinity)	Survival/growth of larval/juvenile tidal-fresh resident fish; protective of threatened/endangered species	February 1-May 31
	Instantaneous minimum ≥ 5 mg/L	Survival and growth of larval/juvenile migratory fish; protective of threatened/endangered species	
	Open-water fish and shellfish designated use criteria apply		June 1-January 31
Shallow - water bay grass use	Open–water fish and shellfish designated criteria apply		Year-round
Open-water fish and shellfish use[1]	30-day mean ≥ 5.5 mg/L (tidal habitats with ≤0.5 salinity)	Growth of tidal-fresh juvenile and adult fish; protective of threatened/endangered species	Year-round
	30-day mean ≥ 5 mg/L (tidal habitats with >0.5 salinity)	Growth of larval, juvenile and adult fish and shellfish; protective of threatened/endangered species	
	7-day mean ≥ 4 mg/L	Survival of open-water fish larvae	
	Instantaneous minimum ≥ 3.2 mg/L	Survival of threatened/endangered sturgeon species[1]	
Deep-water seasonal fish and shellfish use	30-day mean ≥ 3 mg/L	Survival and recruitment of bay anchovy eggs and larvae	June 1-September 30
	1-day mean ≥ 2.3 mg/L	Survival of open-water juvenile and adult fish	
	Instantaneous minimum ≥ 1.7 mg/L	Survival of bay anchovy eggs and larvae	
	Open-water fish and shellfish designated-use criteria apply		October 1-May 31
Deep channel seasonal refuge use	Instantaneous minimum ≥ 1 mg/L	Survival of bottom-dwelling worms and clams	June 1-September 30
	Open-water fish and shellfish designated use criteria apply		October 1-May 31

1. When water column temperatures are greater than 29 °C, an open water dissolved oxygen criterion for the instantaneous minimum of 4.3 mg/L is applied to protect habitat for survival of shortnose sturgeon.

Source: U.S. EPA 2003a

Criteria can be specific to duration and seasonality …

DOCUMENT: Ambient Water Quality Criteria for Dissolved Oxygen, Water Clarity and Chlorophyll a for the Chesapeake Bay and Its Tidal Tributaries: 2017 Technical Addendum

AUTHOR: EPA

YEAR: 2017

NOTES: Update to 2003 Report cited previously. Criteria related to sturgeon protection remain the same.

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… or a "common threshold" approach can be applied to criteria selection

Data presented by researchers and conclusions published by literature reviewers all bottle neck toward a common threshold value of approximately 5 mg/L for freshwater fishes. A prudent and responsible approach to choosing a criterion would not be to accept the highest D.O. concentration where harmful effects are witnessed, but to choose a criterion that prevents D.O. levels from reaching those harmful effects (Fischer 2009)." "Additional stressors such as various pollutions and increased water temperatures during low flow periods would increase this D.O. threshold; therefore, 5 mg/L should be viewed as a value providing a minimal margin of protection to a multi-species warm water fishery throughout all life stages. Such an assertion is supported by the relation of a single criterion of 5 mg/L to the models provided by Doudoroff and Shumway (1970) [and Edwards et al. (1983) specifically for Smallmouth bass] and the conclusions drawn by Coble (1982)". (Fischer 2009).

DOCUMENT: Rationale for the Development of Ambient Water Quality Criteria for Dissolved Oxygen Protection of Aquatic Life Use

AUTHOR: Pennsylvania

YEAR: 2013

NOTES: Document does not directly reference the protection of sturgeon; however, it does discuss the protection of anadromous species in the Delaware like shad

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Evaluation of Thresholds for Atlantic Sturgeon

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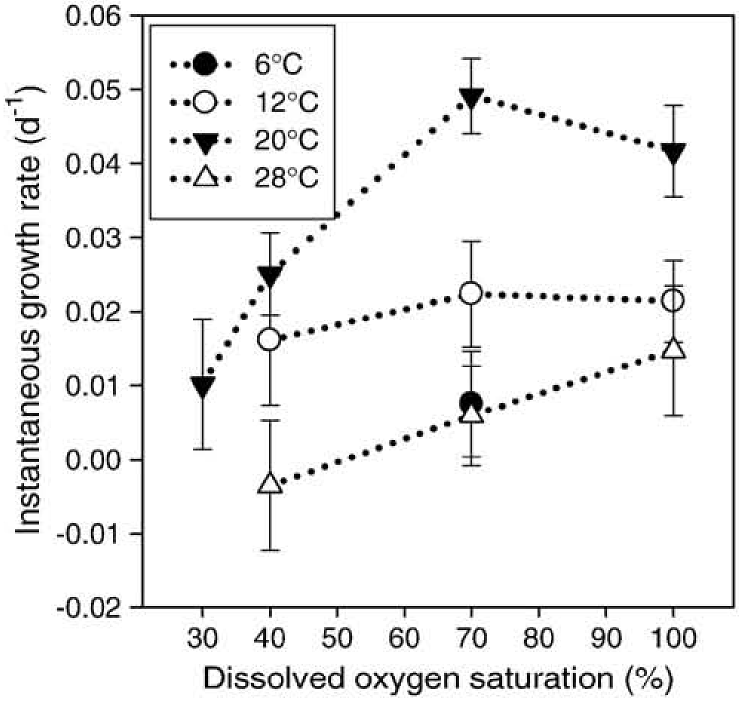
Niklitischek and Secor 2009a: Lab Results

Dissolved oxygen, temperature and salinity effects on the ecophysiology and survival of juvenile Atlantic sturgeon in estuarine waters: I. Laboratory results

Edwin J. Niklitschek [a,*], David H. Secor [b]

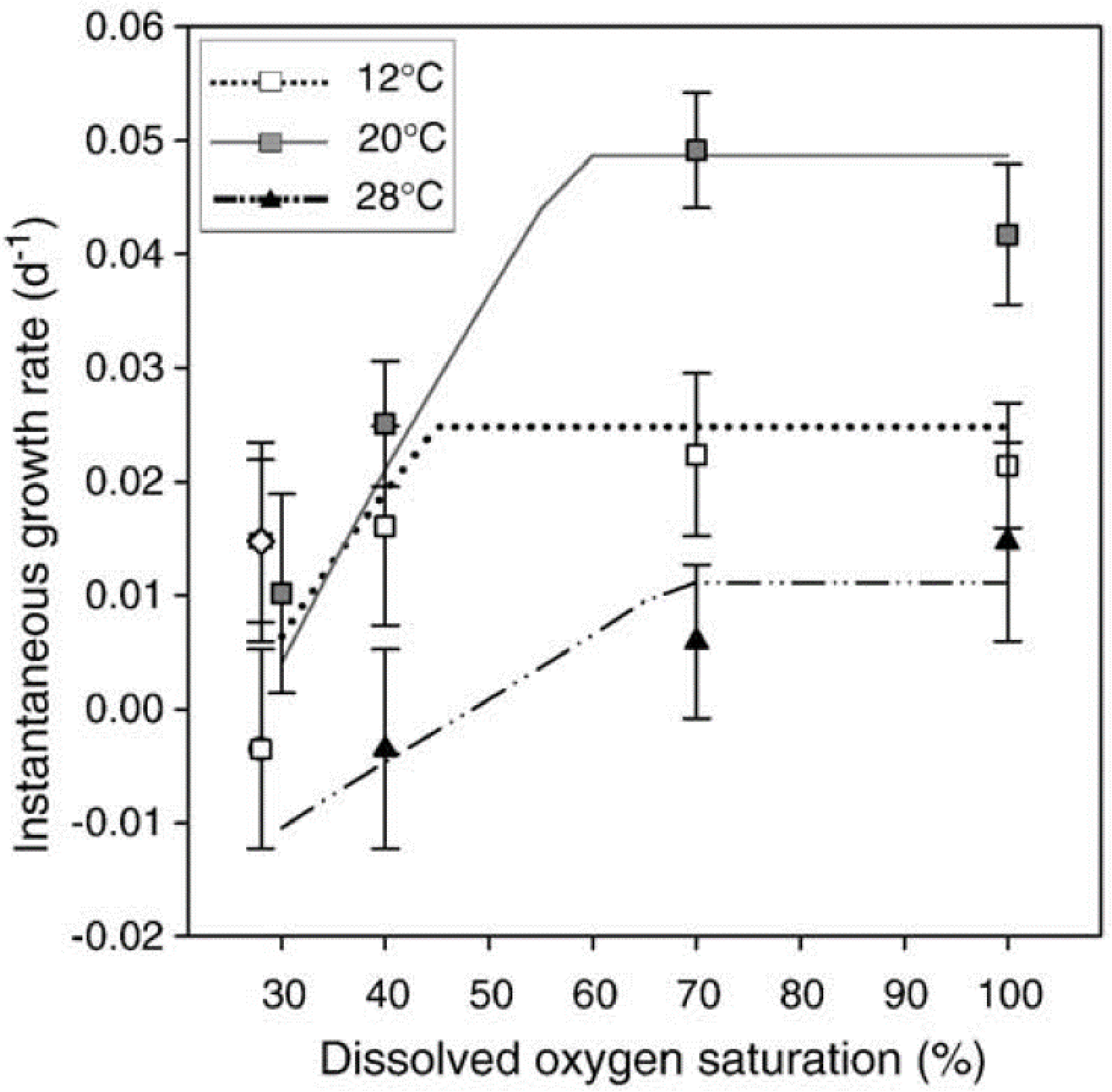


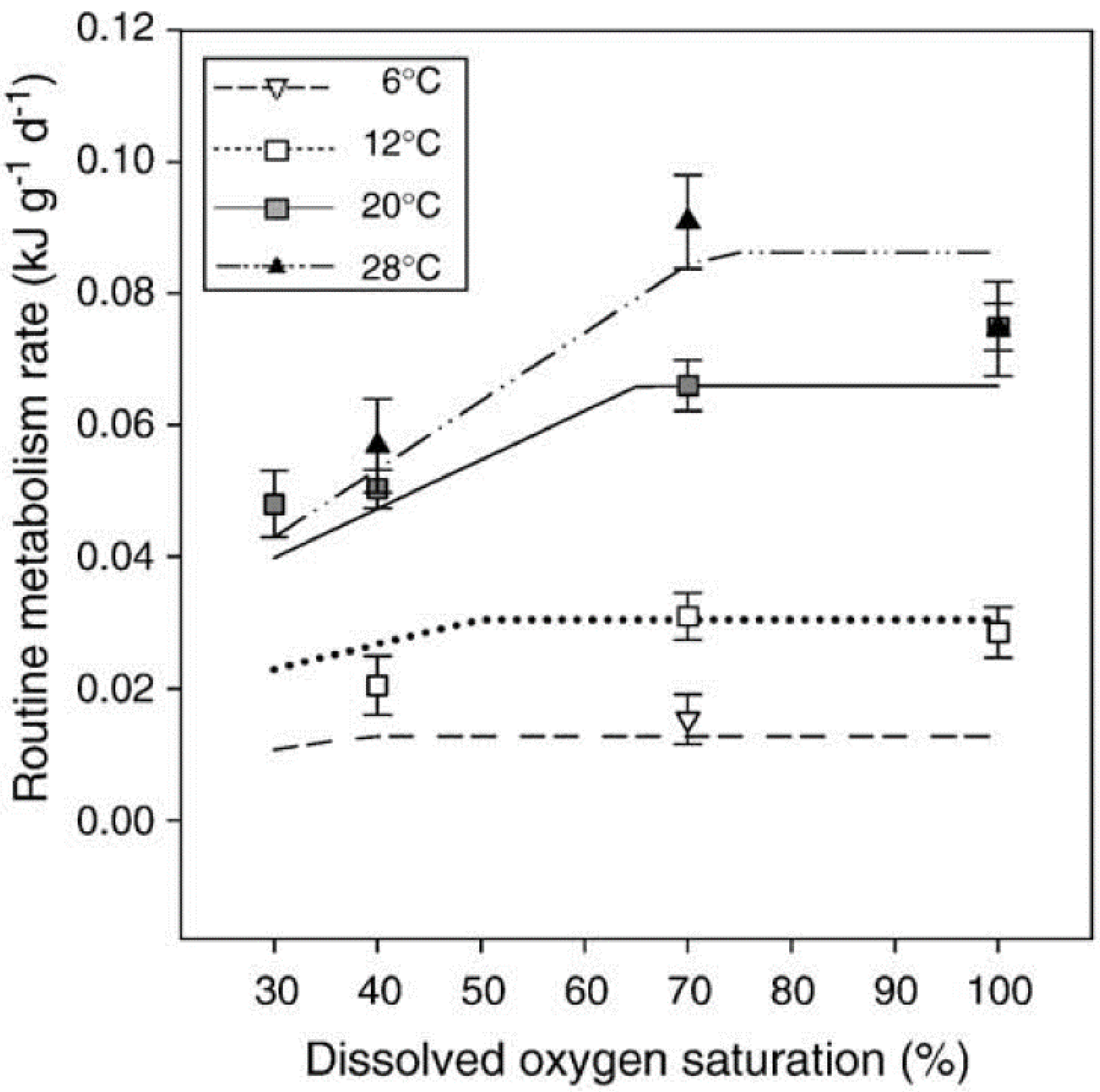
Our results show the importance of considering temperature and salinity as relevant covariates for hypoxia criteria definitions: considering both their effects upon physiological rates and upon oxygen solubility in water and blood (Holeton and Randall, 1967). For illustration purposes, if optimal growth or survival rates were used as criteria to set a hypoxia threshold for juvenile Atlantic sturgeon, that value would rise from 40 to 70% DO_{SAT} if temperature increased from 12 to 20 °C. At salinity 1 these values would correspond to concentrations of 4.3 and 6.3 mg l^{-1}, respectively. At salinity 29, on the other hand, the same thresholds would correspond to concentrations of 3.6 and 5.4 mg l^{-1}, respectively. At this point, it must be emphasized that "percent DO saturation" or "partial pressure of DO" are the biologically relevant factors for hypoxia, since these, rather than oxygen concentration, represent what physically determines fish oxygen uptake from the surrounding water (Cech, 1990; Kiceniuk and Colbourne, 1997).

Niklitischek and Secor 2009b: Bioenergetics Model

Dissolved oxygen, temperature and salinity effects on the ecophysiology and survival of juvenile Atlantic sturgeon in estuarine waters: II. Model development and testing

Edwin J. Niklitschek [a,*], David H. Secor [b]





Niklitischek and Secor 2009b: Bioenergetics Model

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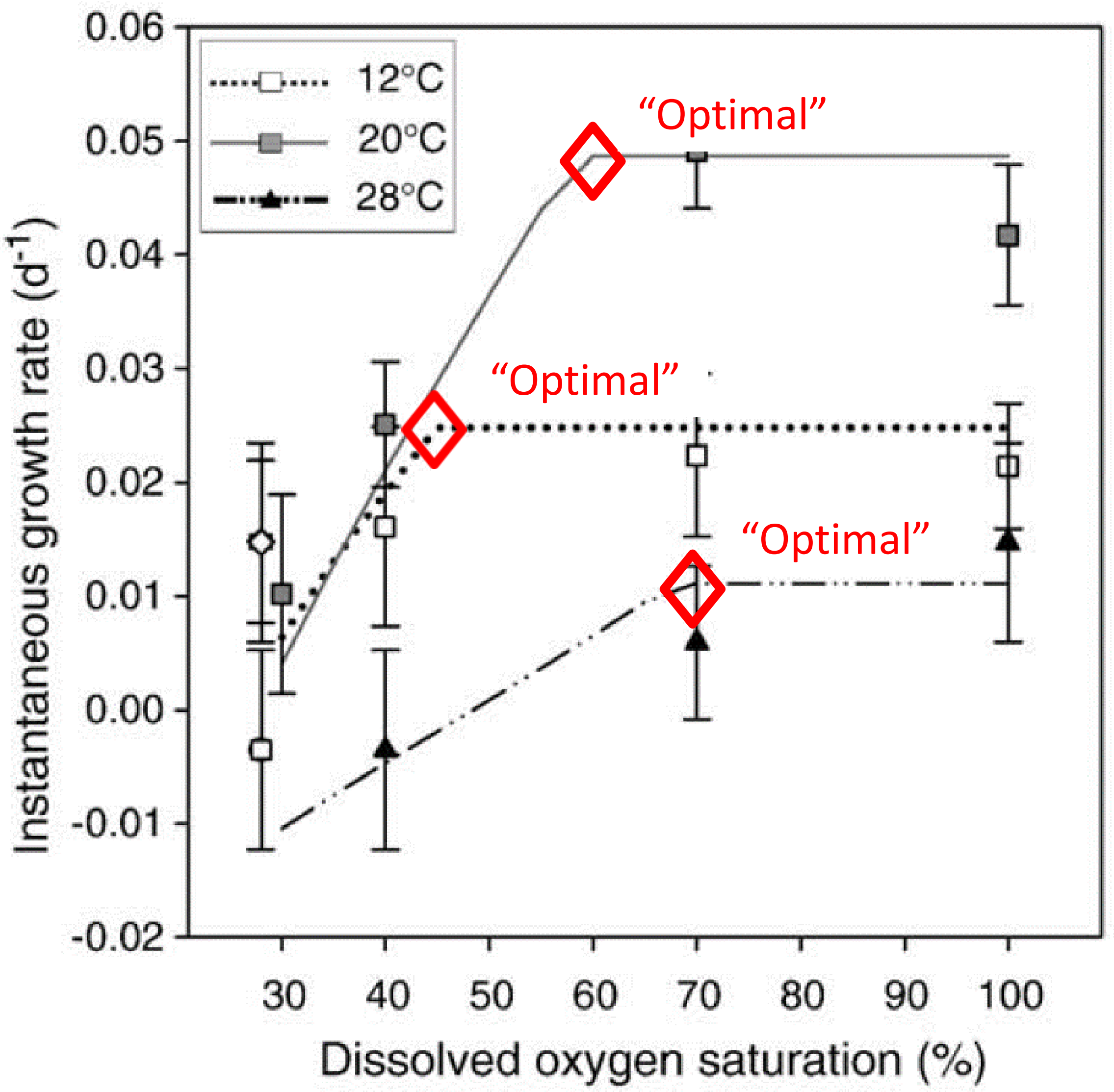
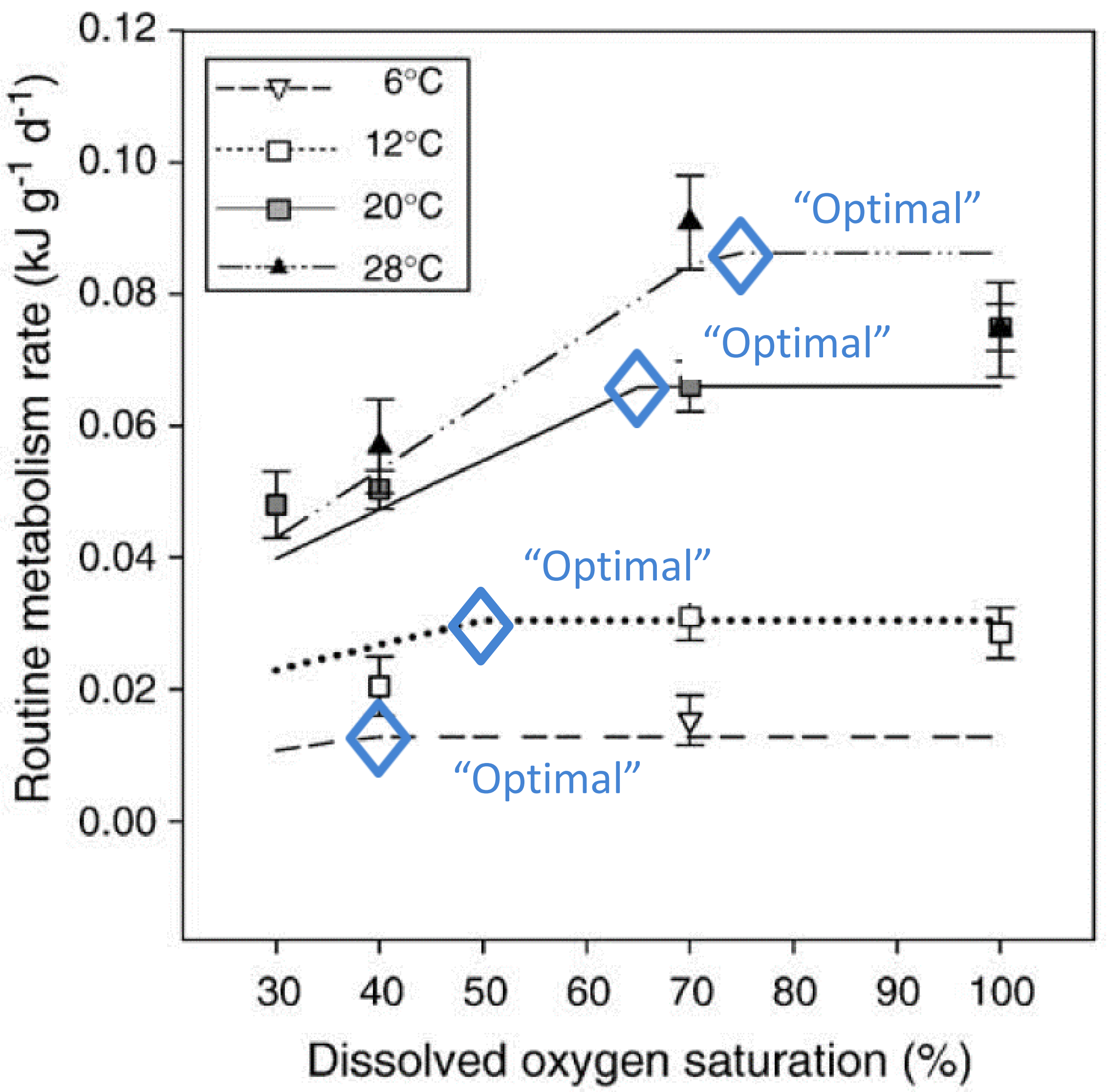
Edwin J. Niklitschek [a,*], David H. Secor [b]

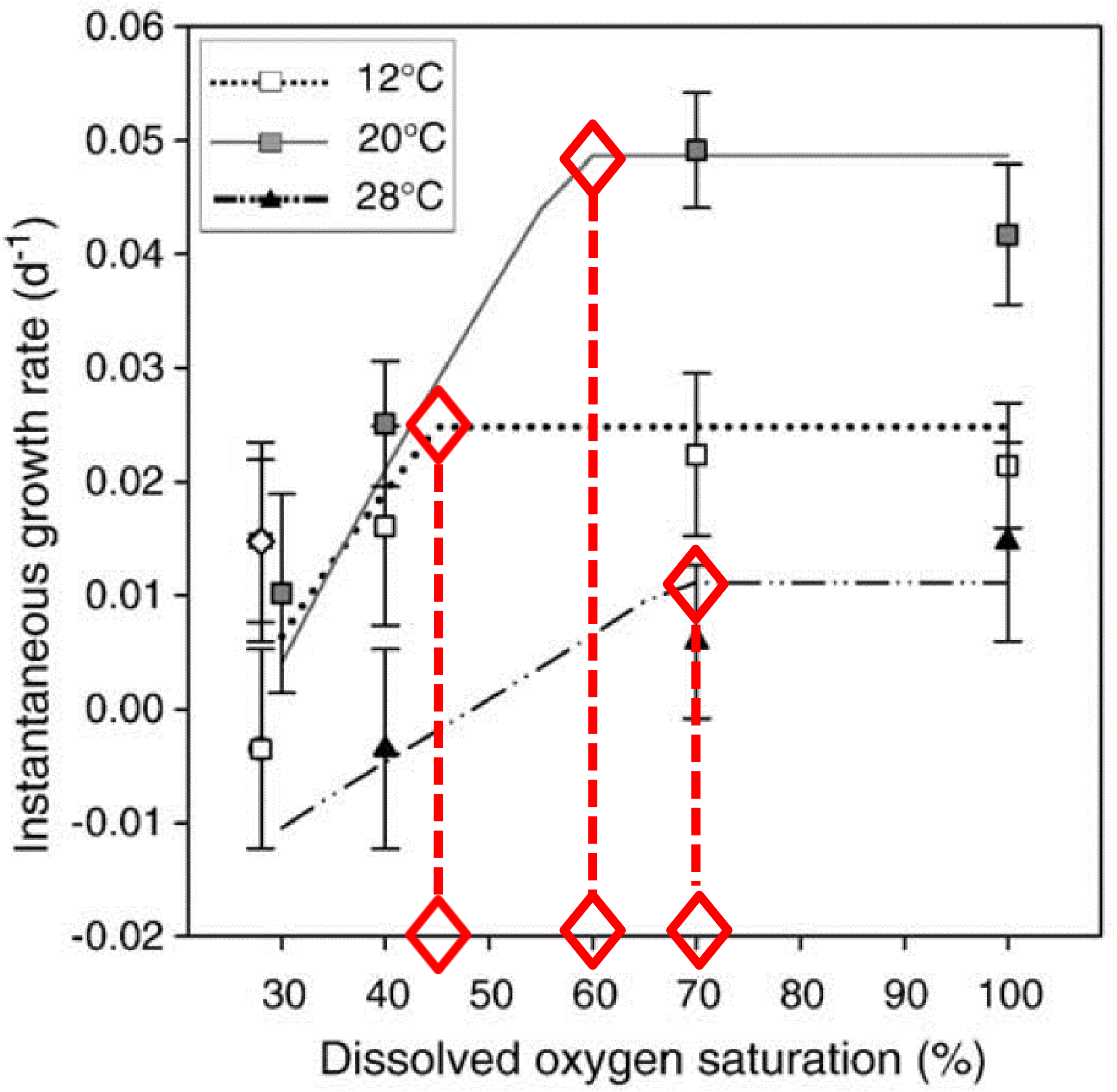


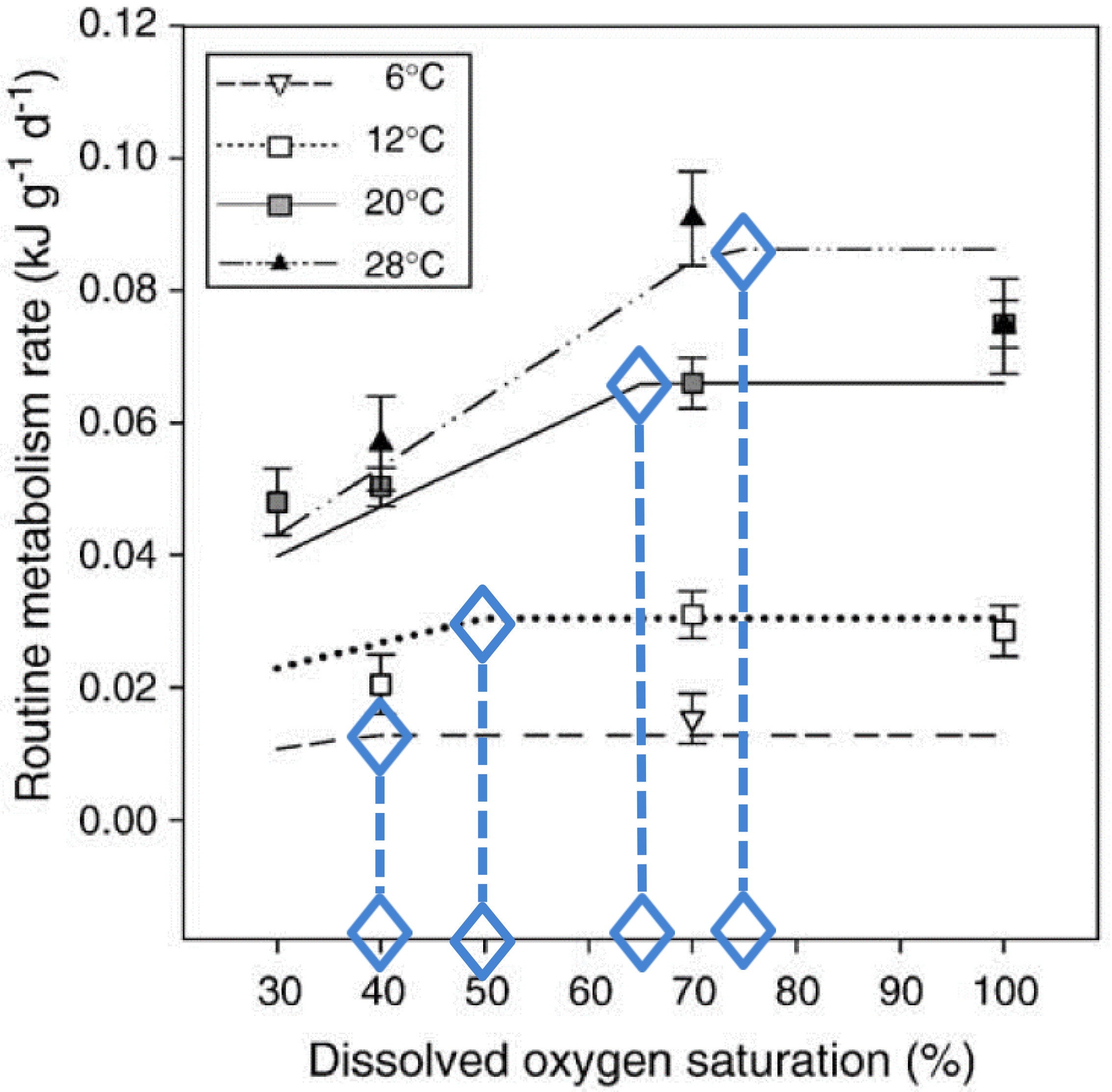


Niklitischek and Secor 2009b: Bioenergetics Model

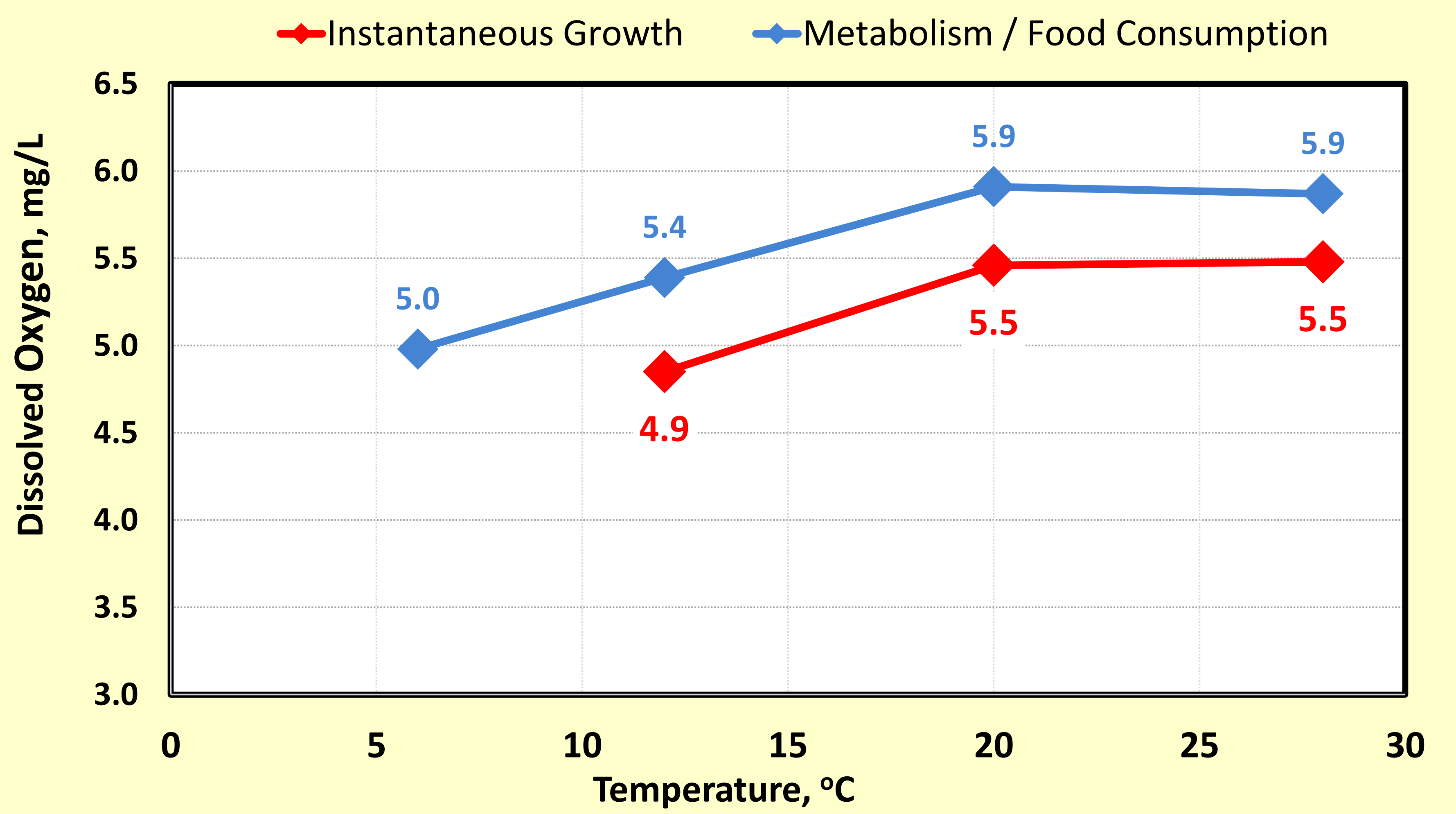
Dissolved oxygen, temperature and salinity effects on the ecophysiology and survival of juvenile Atlantic sturgeon in estuarine waters: II. Model development and testing

Edwin J. Niklitschek [a,*], David H. Secor [b]





Calculated "Optimal" Thresholds for Dissolved Oxygen Concentration at different Temperatures*



*From: *"Dissolved oxygen, temperature and salinity effects on the ecophysiology and survival of juvenile Atlantic sturgeon in estuarine waters: II. Model development and testing,"* Niklitschek and Secor, 2009b

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What about mortality?

- 100% survival observed at 12°C or 100% saturation
- 95% - 100% survival observed for nearly all combinations of temperature and oxygen
- Lower survival observed at 70% DO saturation at 28°C appears to be lab variability
- These data do not point to a DO saturation threshold based on mortality or survival

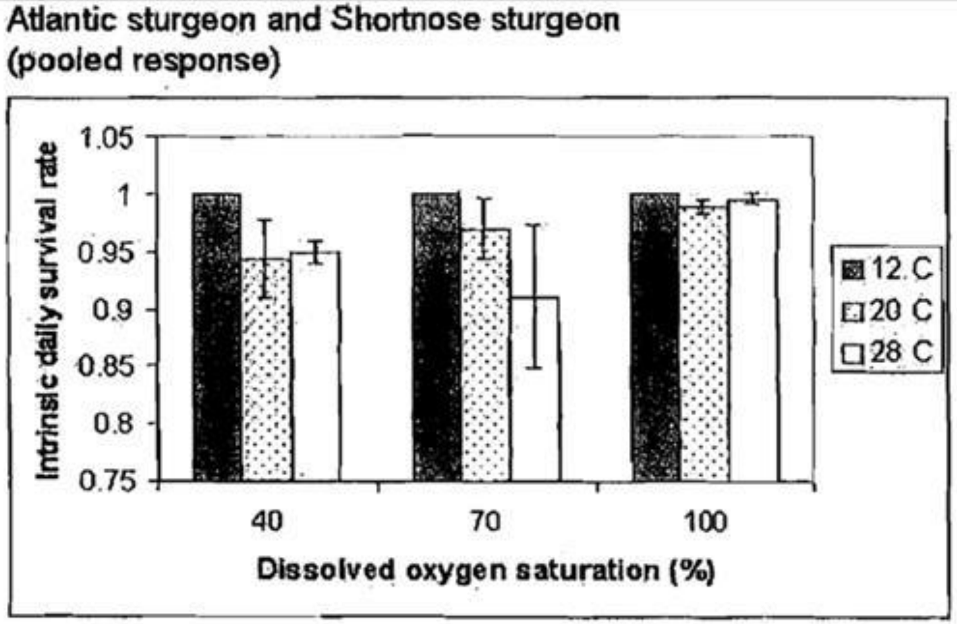

Figure 6. Effect of DO and temperature on long-term survival (20-45 d trials) of Atlantic and shortnose sturgeon young-of-the-year. Laboratory experiments conducted by Niklitschek (2001). Bars represent standard errors.

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What about the NMFS (2017) Habitat Statement?

Physical features essential to conservation of Atlantic Sturgeon

(iii) Larval, juvenile, and subadult growth, development, and recruitment. Appropriate temperature and oxygen values will vary interdependently, and depending on salinity in a particular habitat. For example, 6.0 mg/L DO or greater likely supports juvenile rearing habitat, whereas DO less than 5.0 mg/L for longer than 30 days is less likely to support rearing when water temperature is greater than 25 °C. In temperatures greater than 26 °C, DO greater than 4.3 mg/L is needed to protect survival and growth. Temperatures of 13 to 26 °C likely to support spawning habitat.

Comments/Response

We considered the available information on Atlantic sturgeon growth, and temperature, DO, and salinity (Breitburg, 2002; EPA, 2003; Niklitscheck and Secor 2009; Niklitscheck and Secor 2010; Allen *et al.*, 2014) when we developed the examples provided in the proposed rule. Our intent was to provide an example in the proposed rule of a set of conditions that we expect to correlate to Atlantic sturgeon use of an area; it was not our intent to provide an example of the DO levels that are necessary for the survival of any particular age class of Atlantic sturgeon.

- How this has been mischaracterized?
  - 6 mg/L DO is needed for propagation
- What it actually says
  - Among the physical factors needed to conserve Atlantic Sturgeon is water quality that supports propagation
  - For example, greater than 6 mg/L likely supports juveniles regardless of temperature. DO of 5 and 4.3 are also relevant under different temperatures
- What NOAA Fisheries says it means
  - Descriptions of suitable habitat relate to habitat preference, not growth and development requirements
  - NMFS recommended we not include it as an independent threshold for this exercise
- How DRBC intends to make use of the NMFS work
  - Developing a metric to quantify the time over 6 mg/L for any scenario

How have others interpreted the data in terms of threshold recommendations?

- Atlantic Sturgeon researchers
- Scientists from environmental community

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Modeling the influence of hypoxia on the potential habitat of Atlantic sturgeon *Acipenser oxyrinchus*: a comparison of two methods

Vol. 483: 257–272, 2013
doi: 10.3354/meps10248

MARINE ECOLOGY PROGRESS SERIES
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Published May 30

Atlantic Sturgeon researchers

Adam J. Schlenger[1,*], Elizabeth W. North[1], Zachary Schlag[1], Yun Li[1,5], David H. Secor[2], Katharine A. Smith[3], Edwin J. Niklitschek[4]

Table 1. Required and optimal physiological tolerances used for fixed-criteria thresholds of young-of-the-year and yearling Atlantic sturgeon *Acipenser oxyrinchus*. Criteria were based on a literature review

Analogous to: Unsuitable Suitable

Environmental variable	Physiological tolerance Required	Optimal	Reference(s)
Young-of-the year			
Temperature (°C)	0–28	16–24	Niklitschek & Secor (2005, 2009a), Dovel & Berggren (1983)
Salinity	0–22	3.5–18.5	Niklitschek (2001), Niklitschek & Secor (2005, 2009a),
Dissolved oxygen (mg l^{-1})	3.3	5.0	Niklitschek & Secor (2009a)
Yearling			
Temperature (°C)	0–28	16–24	Niklitschek & Secor (2005, 2009a), Dovel & Berggren (1983)
Salinity	0–29	18.5–25.5	Niklitschek & Secor (2005, 2009a)
Dissolved oxygen (mg l^{-1})	3.3	5.0	Niklitschek & Secor (2009a)

The Nature Conservancy 2016

Atlantic Sturgeon Young-of-Year Growth: Dissolved Oxygen

	DO (mg/l)	Support in literature	Context
Optimal	> 6.0	• In laboratory studies, YOY **growth rates were maximized** when dissolved oxygen concentration was above 70% (6 mg/L @ 25 C) (Niklitschek and Secor 2009). • **Optimal** DO for YOY life stage > 5 mg/L (Greene et al. 2009)	Laboratory, Atlantic sturgeon
Suitable	5.0	• Interpreting existing data and studies , a 60% saturation level, or 5 mg/L @ 25 C was determined to **protect sturgeon from nonlethal effects** in the Chesapeake (EPA 2003).	Meta-analysis; Atlantic sturgeon
	4.7 4.3	• YOY (30 to 200 days) experience **reduced metabolic and feeding rates** with less than 60 % oxygen saturation (4.3 to 4.7 mg/L @ 22C to 27 C)(Secor and Niklitschek 2001).	Laboratory; Atlantic sturgeon
Impaired	4.0	• Based on existing literature and preliminary data on habitat use and recruitment, **not likely support growth and survival** of Atlantic Sturgeon YOY (Kahn and Fisher 2012).	Delaware River, Atlantic sturgeon
Lethal	3.3	• **Mortality** observed during summer temperatures and DO < 3.3 mg/L (Secor and Niklitschek 2001).	Laboratory, Atlantic sturgeon
	3.0	• **Significant mortality** observed (85%) in YOY (90 days) held at 26 C and 3.0 mg/L for 10 days (Secor and Gunderson 1998). During the DO sag in the Delaware , YOY are younger (30 to 60 days) and more sensitive (Campell and Goodman 2004) to change. Also, river temperatures exceed those in the study (30 C in recent years Kahn and Fisher 2012)).	Laboratory, Atlantic sturgeon

Optimal – maximized growth and development

Suitable – supporting growth and development

Impaired –negative effect on physiology or growth

Lethal – documented mortality

Summary of recommended habitat conditions:

To support successful Atlantic sturgeon recruitment in the Delaware River, we recommend*;

- Instantaneous DO ≥ 5.0 mg/L
- Temperature < 28°C
- Salinity < 0.5 ppt, and
- Discharge > July Q85 (4,000 cfs @ Ben Franklin), when average daily DO < 5.5 mg/L

**Recommendations represent the minimum values required to support habitat suitable for recruitment based on best available literature, regional data and expert review. To address cumulative stressors present in the Delaware (e.g. dioxins), conservation measures should be more protective.*

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Status of Atlantic Sturgeon "deeper dive"

Summary

- Still a work in progress
  - Revised thresholds to be formalized in next draft of report
- Thresholds are not critical path for AA
  - They will be used during rulemaking to determine what degree of use can be expected with a particular DO condition
  - Will be important in determining whether HADO can support full 101 uses

Process

- Four meetings so far with co-regulators
- Met with ANSDU author (Rich Horwitz)
- Met with Fish Co-Op twice
- Met with NMFS (NOAA Fisheries)
- Arranging meeting with NMFS, ASFMC, EPA

- DRBC's goal is to determine the highest attainable DO throughout the full range of relevant DO levels

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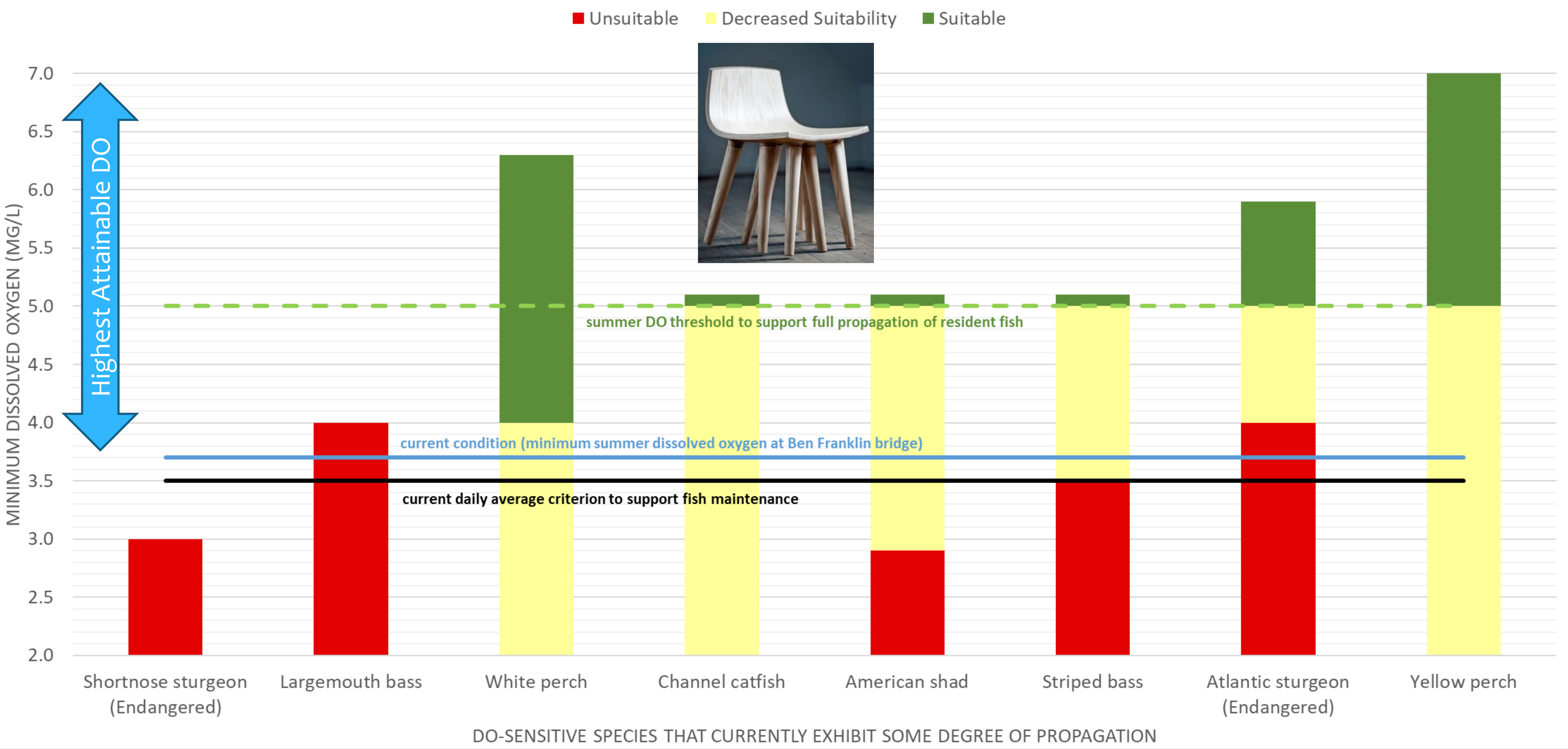
Conceptual model relating aquatic life uses to DO



Reports (July – September)

- Draft Water quality model calibration report
  - Sections of the report are being reviewed by the MEP
- Draft Socio-economic evaluations study report
  - Generic evaluation report is being finalized
  - Selected reduction scenario conditions will be evaluated
- 2nd draft of Linking Aquatic Life Uses with DO Conditions report
  - Continue refine and finalize the 2nd draft
- Draft analysis of attainability
  - Due by September 2022.

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