

1 Supplementary Tables

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3 Table S1: Description of monitoring locations within five National Estuarine Research Reserve System (NERRS) estuaries.

Estuary	Monitoring location	Sonde position above sediment bed (m) ^a	Average water column depth (m) ^a	Approximate mean tidal fluctuation (m) ^a	Tidal Regime ^b	Residual Current Type ^b	Tidal Flow Type ^b	Site characteristics ^a	Approximate residence time
Lake Superior (LKS) NERR	Barker's Island	0.5	2.0	NA	NA	NA	NA	This site is located on the northwest end of Barker's Island in the St. Louis River, upstream of the Superior entry to the estuary. Situated within the lower industrial harbor, the site sits downstream of two wastewater treatment plants and is influenced by Lake Superior seiche.	NA
	Pokegama Bay	0.25	1.0 to 2.0	NA	NA	NA	NA	Situated on the Pokegama River – a red clay tributary whose mouth enters the St. Louis River between Oliver and Blatnik stations – this site lies upstream of the confluence. The area supports large wild rice beds and is influenced by Lake Superior seiches.	NA
	Blatnik Bridge	5.5	7.0	NA	NA	NA	NA	Located on the downstream side of a mid-river bridge protection cell near Rice's Point, this site is situated within the lower estuary's industrial harbor. It sits immediately downstream from the Western Lake Superior Sanitary District wastewater treatment plant outfall and experiences lake seiche influence.	NA
	Oliver Bridge	6.5	8.0	NA	NA	NA	NA	The site is located on the downstream side of the Oliver Bridge, 11 miles upstream of Lake Superior. It receives river flow below the Fond du Lac Dam but is influenced to some extent by Lake Superior seiche.	NA
Chesapeake Bay, Maryland (CBM) NERR	Iron Pot Landing	0.25	1.6	0.6	Minimally tidal	Well-mixed domain	Mixed, semi-diurnal tidal flow	The site is located in the mid-channel of Western Branch River and roughly 1 km downstream of a large (20 MGD) wastewater treatment plant outfall.	NA

Estuary	Monitoring location	Sonde position above sediment bed (m) ^a	Average water column depth (m) ^a	Approximate mean tidal fluctuation (m) ^a	Tidal Regime ^b	Residual Current Type ^b	Tidal Flow Type ^b	Site characteristics ^a	Approximate residence time
(Jug Bay)	Railroad Bridge	0.25	1.4	0.6	Minimally tidal	Well-mixed domain	Semi-diurnal tidal flow	The site is located in the mid-channel of the Patuxent River and the site's water quality is reflective of the general water quality of the main portion of the river. A large wastewater treatment plant (averaging 20 MGD) discharges directly into the Western Branch tributary of the Patuxent River upstream.	NA
	Mataponi Creek	0.25	0.7	0.6	Minimally tidal	Well-mixed domain	Mixed, semi-diurnal tidal flow	The site is located in mid-channel of the Mataponi Creek. Water quality is reflective of the general water quality of the main portion of Mataponi Creek. Potential pollutants are likely driven by agricultural runoff. Dense seasonal submerged aquatic vegetation influences water quality during summer months.	NA
Weeks Bay (WKB) NERR	Magnolia River	0.5	1.1	0.4	NA	NA	NA	This site is located near the mouth of Magnolia River. The land use around this site is bottomland forest and shrub, with a fringing marsh. Upriver land use is substantially residential. The Magnolia River watershed is predominantly agricultural, featuring turf, cotton and peanut crops alongside cattle grazing. There is no indication of pollutants at this site and no submerged aquatic vegetation.	Across the estuary, the average residence time is 13 days under average discharge conditions but can vary from 0.5 to 100 days during high and low-flow conditions. (Stutes et al., 2006)
	Middle Bay	0.5	1.5	0.4	NA	NA	NA	This site is located near the middle of the north-south axis of Weeks Bay. There is no indication of pollutants and no submerged aquatic vegetation at this site.	
	Weeks Bay	0.5	0.9	0.4	NA	NA	NA	This site is located near the southeast shore of Weeks Bay. The land use around this site is almost exclusively residential, with agriculture occurring inland.	
	Fish River	0.5	2.0	0.4	Microtidal	Partially mixed domain	Diurnal tidal flow	This site is located near the mouth of the Fish River. Directly surrounding the site, land use is residential and forested.	
Guana Tolomato Matanzas (GTM) NERR	San Sebastian	1.0	4.1	1.5	Moderately tidal	Well-mixed domain	Mixed, semi-diurnal tidal flow	The site is located at the confluence of the San Sebastian and Matanzas Rivers, approximately 4 km south of the St. Augustine Inlet. The San Sebastian River drains an urbanized watershed in the western portion of St. Augustine; it is characterized by both residential and commercial development including five marinas and a wastewater treatment facility.	2–6 days (Gray et al., 2022; Sheng et al., 2008)

Estuary	Monitoring location	Sonde position above sediment bed (m) ^a	Average water column depth (m) ^a	Approximate mean tidal fluctuation (m) ^a	Tidal Regime ^b	Residual Current Type ^b	Tidal Flow Type ^b	Site characteristics ^a	Approximate residence time
	Pine Island	1.0	3.3	1.6	Moderately tidal	Well-mixed domain	Mixed, semi-diurnal tidal flow	This site is located within the Guana River Marsh Aquatic Preserve in the northern section of the GTMNERR. The site lies within Class II Shellfish Harvesting Waters.	15–16 days (Gray et al., 2022; Sheng et al., 2008)
	Pellicer Creek	1.0	1.4	0.5	Moderately tidal	Salt wedge domain	Mixed, semi-diurnal tidal flow	This site is located at the end of a recreational dock in Faver-Dykes State Park within the Pellicer Creek Aquatic Preserve in the southern section of the GTMNERR. This site is tidal and bordered for much of its length by publicly owned conservation lands.	3–18 days (Gray et al., 2022; Sheng et al., 2008)
	Fort Matanzas	1.0	2.4	1.2	Moderately tidal	Well-mixed domain	Mixed, semi-diurnal tidal flow	This site is approximately 4 km north of the Matanzas Inlet and near a shoreline on Anastasia Island that is undergoing residential development. The site lies within Class II Shellfish Harvesting Waters.	2–9 days (Gray et al., 2022; Sheng et al., 2008)
San Francisco Bay (SFB) NERR	First Mallard	0.25 - 0.5	0.66 to 2.94	-0.3 to 1.8	Moderately tidal	Well-mixed domain	Mixed, semi-diurnal tidal flow	This site is located within the Rush Ranch Open Space Preserve, situated in the brackish portion of the estuary in western Suisun Marsh north of Suisun Bay. Known inputs of pollutants and nutrients at Rush Ranch include runoff from roads, ranchlands, regional wastewater discharge, and localized boating and hunting. The approximate mean tidal fluctuation is reported relative to mean lower low water based on 2012 NOAA tide predictions.	< 1 day to weeks (Walters et al., 1985)
	Second Mallard	0.25 - 0.5	0.82 to 3.10	-0.3 to 1.8	Moderately tidal	Well-mixed domain	Mixed, semi-diurnal tidal flow	This site is located within the Rush Ranch Open Space Preserve, situated in the brackish portion of the estuary in western Suisun Marsh north of Suisun Bay. Known inputs of pollutants and nutrients at Rush Ranch include runoff from roads, ranchlands, regional wastewater discharge, and localized boating and hunting. The approximate mean tidal fluctuation is reported relative to mean lower low water based on 2012 NOAA tide predictions.	
	Gallinas Creek	0.25 - 0.5	0.59 to 3.13	-0.5 to 2.1	Moderately tidal	Well-mixed domain	Mixed, semi-diurnal tidal flow	This site is located in Gallinas Creek, a small tidal creek that meets San Pablo Bay just outside the northern boundary of the reserve at China Camp State Park. Draining both forest uplands and developed low-lying areas, Gallinas Creek is relatively heavily impacted by upstream wastewater discharge, urban development lining one edge of the creek, while natural vegetation	

Estuary	Monitoring location	Sonde position above sediment bed (m) ^a	Average water column depth (m) ^a	Approximate mean tidal fluctuation (m) ^a	Tidal Regime ^b	Residual Current Type ^b	Tidal Flow Type ^b	Site characteristics ^a	Approximate residence time
								lines much of the other side. The approximate mean tidal fluctuation is reported relative to mean lower low water, based on 2012 NOAA tide predictions.	
	China Camp	0.25 - 0.5	0 to 2.52	-0.5 to 2.1	Moderately tidal	Well-mixed domain	Mixed, semi-diurnal tidal flow	This site is located within China Camp State Park in western San Pablo Bay and captures water quality information most representative of the marine-influenced portion of the estuary. The site experiences a mix of freshwater runoff from forested uplands and developed low-lying areas, with road runoff serving as an important pollutant. The approximate mean tidal fluctuation is reported relative to mean lower low water, based on 2012 NOAA tide predictions.	

^a Information obtained from the metadata files downloaded from <https://cdmo.baruch.sc.edu/get/landing.cfm> at the time of data request (NOAA National Estuarine Research Reserve System (NERRS), 2023).

^b Information obtained from the Federal Geographic Data Committee (2012) [report](#).

5 **Table S2:** Land use/land cover (LULC) within the watersheds of five estuaries in the National Estuarine Research Reserve System.

LULC class	Percent LULC within estuary watershed					
	<i>Lake Superior (LKS) NERR</i>	<i>Chesapeake Bay, Maryland (CBM - Jug Bay) NERR</i>	<i>Guana Tolomato Matanzas (GTM) NERR</i>	<i>Weeks Bay (WKB) NERR</i>	<i>San Francisco Bay (SFB) NERR</i>	
					<i>San Pablo Bay</i>	<i>Suisun Bay</i>
Water	3.62	0.97	6.78	2.19	5.02	2.32
Tree cover	73.10	38.34	45.67	39.58	26.47	0.80
Flooded vegetation	0.20	0.22	9.48	0.02	1.30	11.78
Crops	0.90	8.14	0.19	27.35	16.62	26.38
Built area	2.75	44.41	28.43	23.80	33.06	18.14
Bare ground	0.20	0.16	0.20	0.09	0.10	1.35
Rangeland	19.22	7.75	9.24	6.96	17.39	39.22
Watershed area (km ²)	11,704	1,393	921	524	114	378
Estimated population within the area (number of people)	167,164	670,180	288,031	58,937	49,622	134,972
Population density (people per km ²)	14	481	312	112	435	356
LULC definitions per Esri (Karra et al., 2021): Water – areas where water is present throughout the year, excluding human-made structures like docks. Tree cover – vegetation with a closed or dense canopy ≥ 15 meters in height. Flooded vegetation – areas where water and vegetation intermix, which are flooded seasonally or predominantly throughout the year. Crops – human-planted vegetation (e.g., cereals, grasses, and crops) that does not reach tree height. Built area – human-made structures, including roads, railroad networks, parking spaces, and industrial and residential buildings. Bare ground – areas dominated by rock, soil, sand (e.g., deserts) with sparse-to-no vegetation throughout the year. Rangeland – homogeneous grasses, mixes of vegetation below tree-height with rock and soil, or forest clearings.						

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7 **Table S3:** Datetime and threshold values for major precipitation events, and breakdown of the number of events during wet and dry
8 years at each National Estuarine Research Reserve (NERR) station.

NERR Station	Date-time used to select dissolved oxygen and precipitation measurements to calculate the resistance index		Precipitation event (mm)	Wet/Dry year	Precipitation threshold (mm/day)
	Prior to precipitation (C ₀)	During and post-precipitation (P ₀)			
Lake Superior, WI (LKS) NERR	2017/06/24 00:00:00 -2017/06/27 23:45:00 2017/07/30 00:00:00 -2017/08/02 23:45:00 2017/08/23 00:00:00 -2017/08/25 23:45:00 2017/09/29 00:00:00 -2017/10/01 23:45:00	2017/06/28 06:00:00 -2017/06/29 23:45:00 2017/08/03 00:00:00 -2017/08/04 23:45:00 2017/08/26 00:00:00 -2017/08/28 23:45:00 2017/10/02 00:00:00 -2017/10/05 23:45:00	34.4 38.1 61.0 44.2	Wet (4)	> 25
	2020/07/14 00:00:00 -2020/07/17 23:45:00 2020/07/14 00:00:00 -2020/07/17 23:45:00 2020/08/04 00:00:00 -2020/08/06 23:45:00	2020/07/18 00:00:00 -2020/07/19 23:45:00 2020/07/21 00:00:00 -2020/07/23 23:45:00 2020/08/07 12:00:00 -2020/08/11 23:45:00	42.9 29.6 74.9	Dry (3)	
Chesapeake Bay, MD (CBM) NERR	2018/05/10 00:00:00 -2018/05/11 12:00:00 2018/05/24 00:00:00 -2018/05/26 23:45:00 2018/05/24 00:00:00 -2018/05/26 23:45:00 2018/06/16 00:00:00 -2018/06/18 23:45:00 2018/07/13 00:00:00 -2018/07/16 23:45:00 2018/09/04 00:00:00 -2018/09/06 23:45:00 2018/09/13 00:00:00 -2018/09/15 23:45:00	2018/05/16 00:00:00 -2018/05/21 23:45:00 2018/05/27 15:00:00 -2018/05/28 23:45:00 2018/06/03 06:00:00 -2018/06/07 23:45:00 2018/06/19 12:00:00 -2018/06/25 23:45:00 2018/07/21 12:00:00 -2018/07/27 23:45:00 2018/09/09 00:00:00 -2018/09/10 23:45:00 2018/09/23 00:00:00 -2018/09/25 23:45:00	117.1 40.2 56.2 41.8 218.1 49.1 58.6	Wet (7)	> 25
	2016/06/24 00:00:00 -2016/06/27 23:45:00 2016/09/15 00:00:00 -2016/09/18 23:45:00 2016/09/23 00:00:00 -2016/09/25 23:45:00	2016/07/01 12:00:00 -2016/07/02 23:45:00 2016/09/19 00:00:00 -2016/09/19 23:45:00 2016/09/28 00:00:00 -2016/09/30 23:45:00	41.0 25.2 76.4	Dry (3)	
Guana Tolomato Matanzas, FL (GTM)	2017/08/19 00:00:00 -2017/08/22 23:45:00	2017/09/10 00:00:00 -2017/09/21 23:45:00	222.9	Wet (3)	*
	2017/08/19 00:00:00 -2017/08/22 23:45:00	2017/09/30 00:00:00 -2017/10/13 23:45:00	270.7		

NERR Station	Date-time used to select dissolved oxygen and precipitation measurements to calculate the resistance index		Precipitation event (mm)	Wet/Dry year	Precipitation threshold (mm/day)
	Prior to precipitation (C ₀)	During and post-precipitation (P ₀)			
NERR	2017/11/15 00:00:00 -2017/11/22 23:45:00	2017/11/23 00:00:00 -2017/11/25 23:45:00	123.1		
	2016/06/01 00:00:00 -2016/06/04 23:45:00 2016/08/21 00:00:00 -2016/08/27 23:45:00 2016/09/05 00:00:00 -2016/09/08 23:45:00 2016/09/21 00:00:00 -2016/09/25 23:45:00	2016/06/05 12:00:00 -2016/06/07 23:45:00 2016/08/28 00:00:00 -2016/09/06 23:45:00 2016/09/14 00:00:00 -2016/09/19 23:45:00 2016/09/28 00:00:00 -2016/10/17 23:45:00	127.9 67.2 27.3 193.3	Dry (4)	
Weeks Bay, AL (WKB) NERR	2018/05/19 00:00:00 -2018/05/22 23:45:00 2018/06/07 00:00:00 -2018/06/09 23:45:00 2018/06/28 00:00:00 -2018/06/30 23:45:00 2018/07/12 00:00:00 -2018/07/14 23:45:00 2018/08/25 00:00:00 -2018/08/26 23:45:00 2018/08/25 00:00:00 -2018/08/26 23:45:00 2018/09/19 00:00:00 -2018/09/20 23:45:00 2018/09/19 00:00:00 -2018/09/20 23:45:00	2018/05/23 00:00:00 -2018/05/27 23:45:00 2018/06/11 00:00:00 -2018/06/13 23:45:00 2018/07/01 12:00:00 -2018/07/09 23:45:00 2018/07/16 09:00:00 -2018/07/18 23:45:00 2018/09/01 00:00:00 -2018/09/03 23:45:00 2018/09/04 00:00:00 -2018/09/08 23:45:00 2018/09/21 12:00:00 -2018/09/23 23:45:00 2018/09/24 00:00:00 -2018/09/29 23:45:00	90.9 47.0 86.3 53.7 56.6 128.6 46.7 66.5	Wet (8)	> 30
	2019/04/01 00:00:00 -2019/04/03 23:45:00 2019/04/15 00:00:00 -2019/04/17 23:45:00 2019/06/01 00:00:00 -2019/06/04 23:45:00 2019/06/20 00:00:00 -2019/06/25 23:45:00 2019/08/07 00:00:00 -2019/08/10 23:45:00 2019/08/22 00:00:00 -2019/08/24 23:45:00 2019/10/21 00:00:00 -2019/10/24 23:45:00	2019/04/04 09:00:00 -2019/04/04 23:45:00 2019/04/26 15:00:00 -2019/04/28 23:45:00 ^a 2019/06/06 00:00:00 -2019/06/13 23:45:00 2019/07/13 00:00:00 -2019/07/15 23:45:00 2019/08/15 12:00:00 -2019/08/16 23:45:00 2019/08/26 06:00:00 -2019/08/27 06:00:00 2019/10/30 00:00:00 -2019/11/01 23:45:00	40.0 32.9 116.1 89.1 37.0 48.2 61.8	Dry (7)	
San Francisco Bay, CA	2017/01/01 00:00:00 -2017/01/02 06:00:00	2017/01/03 00:00:00 -2017/01/06 00:00:00	38.7	Wet (5)	> 20

NERR Station	Date-time used to select dissolved oxygen and precipitation measurements to calculate the resistance index		Precipitation event (mm)	Wet/Dry year	Precipitation threshold (mm/day)
	Prior to precipitation (C ₀)	During and post-precipitation (P ₀)			
(SFB) NERR	2017/01/01 00:00:00 -2017/01/02 06:00:00	2017/01/07 00:00:00 -2017/01/12 23:45:00	126.4		
	2017/01/01 00:00:00 -2017/01/02 06:00:00	2017/01/18 00:00:00 -2017/01/25 00:00:00	110.8		
	2017/03/11 00:00:00 -2017/03/17 23:45:00	2017/03/20 00:00:00 -2017/03/23 23:45:00	43.0		
	2017/04/01 00:00:00 -2017/04/05 06:00:00	2017/04/06 20:00:00 -2017/04/07 23:45:00	20.6		
	2018/01/06 00:00:00 -2018/01/07 23:45:00	2018/01/08 00:00:00 -2018/01/09 23:45:00 ^b	73.6	Dry (3)	
	2018/02/20 00:00:00 -2018/02/23 23:45:00	2018/03/01 00:00:00 -2018/03/01 23:45:00	30.7		
	2018/04/04 12:00:00 -2018/04/05 12:00:00	2018/04/06 00:00:00 -2018/04/07 23:45:00	54.6		
^a GTM NERR: The selected events for 2016 were Hurricanes Colin, Hermine, and Matthew and Tropical Storm Julia. For 2017, the selected events were Hurricane Irma and two Nor’easters. ^a WKB NERR: The resistance calculation excludes dissolved oxygen measurements during the April 25, 2019 precipitation event due to missing data at the Middle Bay monitoring location; only post-event dissolved oxygen measurements were available. ^b SFB NERR: Dissolved oxygen data for the Second Mallard site are missing. No resistance was calculated for this site during that period.					

10 **Table S4:** Pre-disturbance (C_0) and post-disturbance (P_0) dissolved oxygen (mg L^{-1}) and the
11 resistance index values for each major precipitation event across all monitoring locations at five
12 estuaries. Provided as a CSV file.
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14 **Table S5:** Resulting statistical parameters for linear regression analysis conducted for low- and
 15 high-salinity groups and at the continental scale for five estuaries (this table accompanies Fig. 3).

Predictor variables regressed against mean resistance index values	Linear regression parameters: Coefficient of determination (R^2) Significance value (p)		
	<i>Low-salinity group</i>	<i>High-salinity group</i>	<i>Continental scale</i>
Turbidity (NTU)	$R^2 = 0.00$ $p = 0.967$	$R^2 = \mathbf{0.28}$ $p < \mathbf{0.0001}$	$R^2 = \mathbf{0.06}$ $p = \mathbf{0.0014}$
Salinity (ppt)	$R^2 = \mathbf{0.23}$ $p < \mathbf{0.0001}$	$R^2 = 0.01$ $p = 0.48$	$R^2 = 0.00$ $p = 0.64$
Water temperature ($^{\circ}\text{C}$)	$R^2 = \mathbf{0.36}$ $p < \mathbf{0.0001}$	$R^2 = \mathbf{0.58}$ $p < \mathbf{0.0001}$	$R^2 = \mathbf{0.42}$ $p < \mathbf{0.0001}$
Water column depth (m)	$R^2 = \mathbf{0.20}$ $p < \mathbf{0.0001}$	$R^2 = 0.00$ $p = 0.96$	$R^2 = \mathbf{0.11}$ $p < \mathbf{0.0001}$
$\log(\text{DIN} [\text{mg-N L}^{-1}])$	$R^2 = 0.06$ $p = 0.251$	$R^2 = \mathbf{0.54}$ $p = \mathbf{0.004}$	$R^2 = \mathbf{0.12}$ $p = \mathbf{0.037}$
PO_4^{3-} (mg-P L^{-1})	$R^2 = 0.04$ $p = 0.37$	$R^2 = 0.31$ $p = 0.062$	$R^2 = 0.08$ $p = 0.11$
N:P	$R^2 = 0.13$ $p = 0.097$	$R^2 = \mathbf{0.80}$ $p < \mathbf{0.0001}$	$R^2 = 0.08$ $p = 0.105$
Chl a ($\mu\text{g L}^{-1}$)	$R^2 = \mathbf{0.49}$ $p < \mathbf{0.0001}$	$R^2 = \mathbf{0.32}$ $p = \mathbf{0.042}$	$R^2 = \mathbf{0.43}$ $p < \mathbf{0.0001}$
Trees (%)	$R^2 = 0.00$ $p = 0.77$	$R^2 = \mathbf{0.45}$ $p = \mathbf{0.012}$	$R^2 = 0.03$ $p = 0.34$
Crops (%)	$R^2 = 0.19$ $p = 0.031$	$R^2 = 0.04$ $p = 0.4$	$R^2 = 0.04$ $p = 0.51$
Built area (%)	$R^2 = 0.04$ $p = 0.342$	$R^2 = \mathbf{0.73}$ $p = \mathbf{0.0002}$	$R^2 = \mathbf{0.16}$ $p = \mathbf{0.014}$
Population density (ppl km^{-2})	$R^2 = \mathbf{0.18}$ $p = \mathbf{0.033}$	$R^2 = \mathbf{0.73}$ $p = \mathbf{0.0002}$	$R^2 = \mathbf{0.29}$ $p < \mathbf{0.001}$
Note: Significant correlations (i.e., $p < 0.05$) are shown in bold.			

17 **Supplementary figures.**

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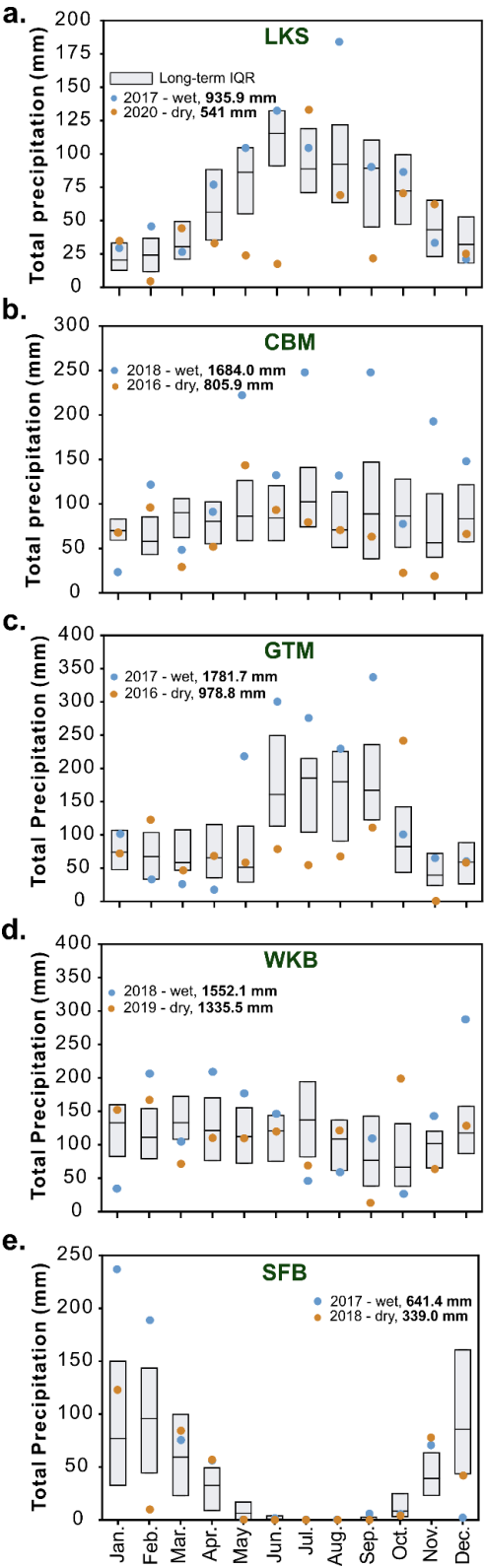
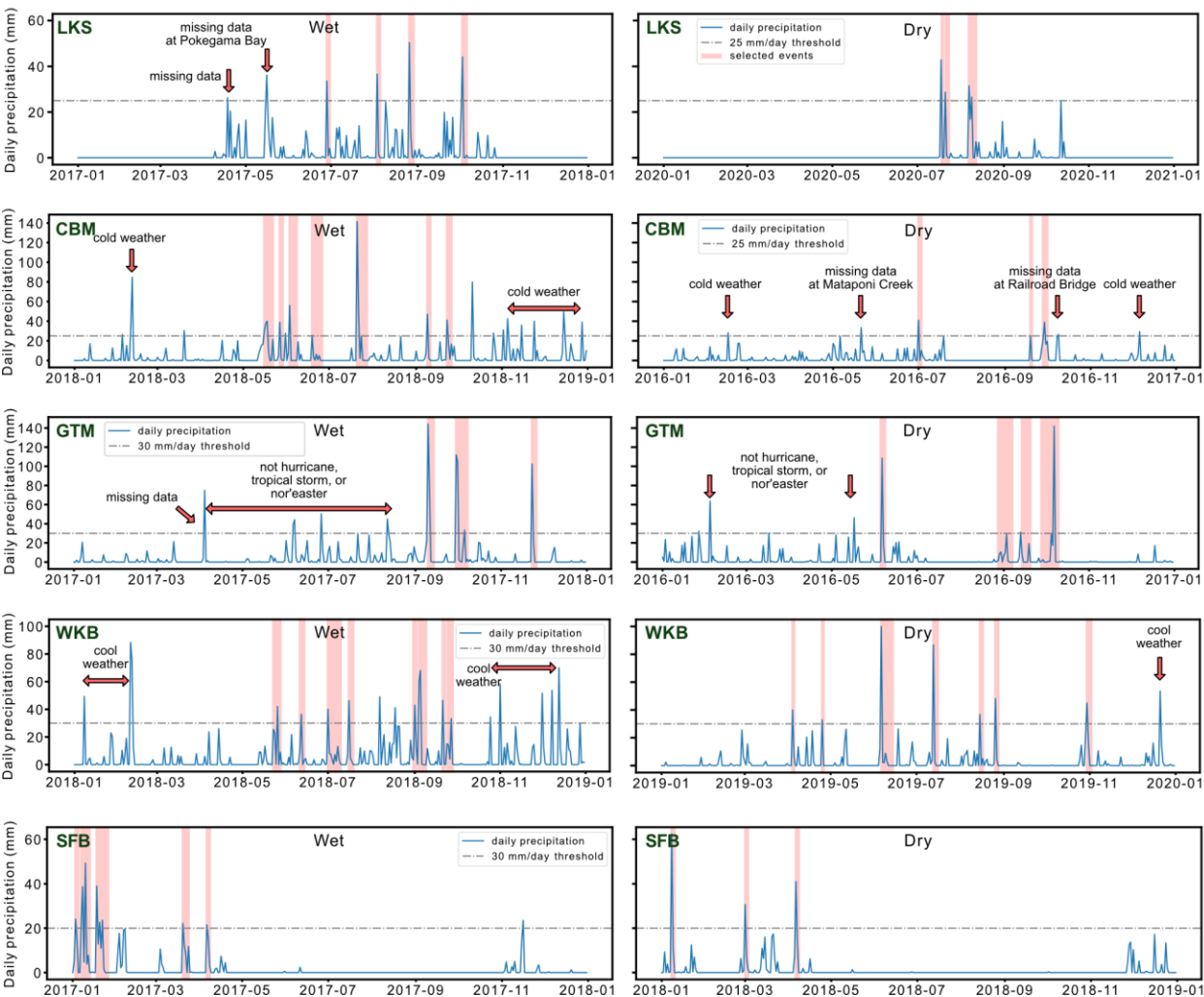


Figure S1: The long-term (30-year) interquartile range and monthly precipitation during relatively wet and dry years. Long-term precipitation data were obtained from airports located in the vicinity of each selected estuarine station. (a) Precipitation record from the Duluth International airport was used to infer wet/dry years at the Lake Superior (LKS NERR) station. (b) The Washington Reagan International Airport precipitation record was used for the Chesapeake Bay, Maryland (CBM NERR) (Jug Bay only) station. (c) The Jacksonville International Airport precipitation record was used for the Guana Tolomato Matanzas (GTM NERR) station. (d) The Birmingham Airport precipitation record was used for the Weeks Bay (WKS NERR) station. (e) The San Francisco International Airport precipitation record was used for the San Francisco Bay (SFB NERR) station.

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Figure S2: Major precipitation events for each estuary during selected wet and dry years. The major precipitation events (shaded in red) were identified by plotting National Estuarine Research Reserve (NERR) precipitation data collected at each estuary. The events were down-selected based on water quality data availability for each estuary, seasonal timing (generally within warmer seasons), and whether the event was noted in NERR metadata sheets and/or reported as a hurricane, tropical storm, nor'easter, or other major weather event. Estuary abbreviations: Lake Superior (LKS) NERR, Chesapeake Bay, Maryland (Jug Bay only) NERR, Guana Tolomato Matanzas (GTM) NERR, Weeks Bay (WKB) NERR, and San Francisco Bay (SFB) NERR. For details about the events used for resistance index calculations, see Table S3.

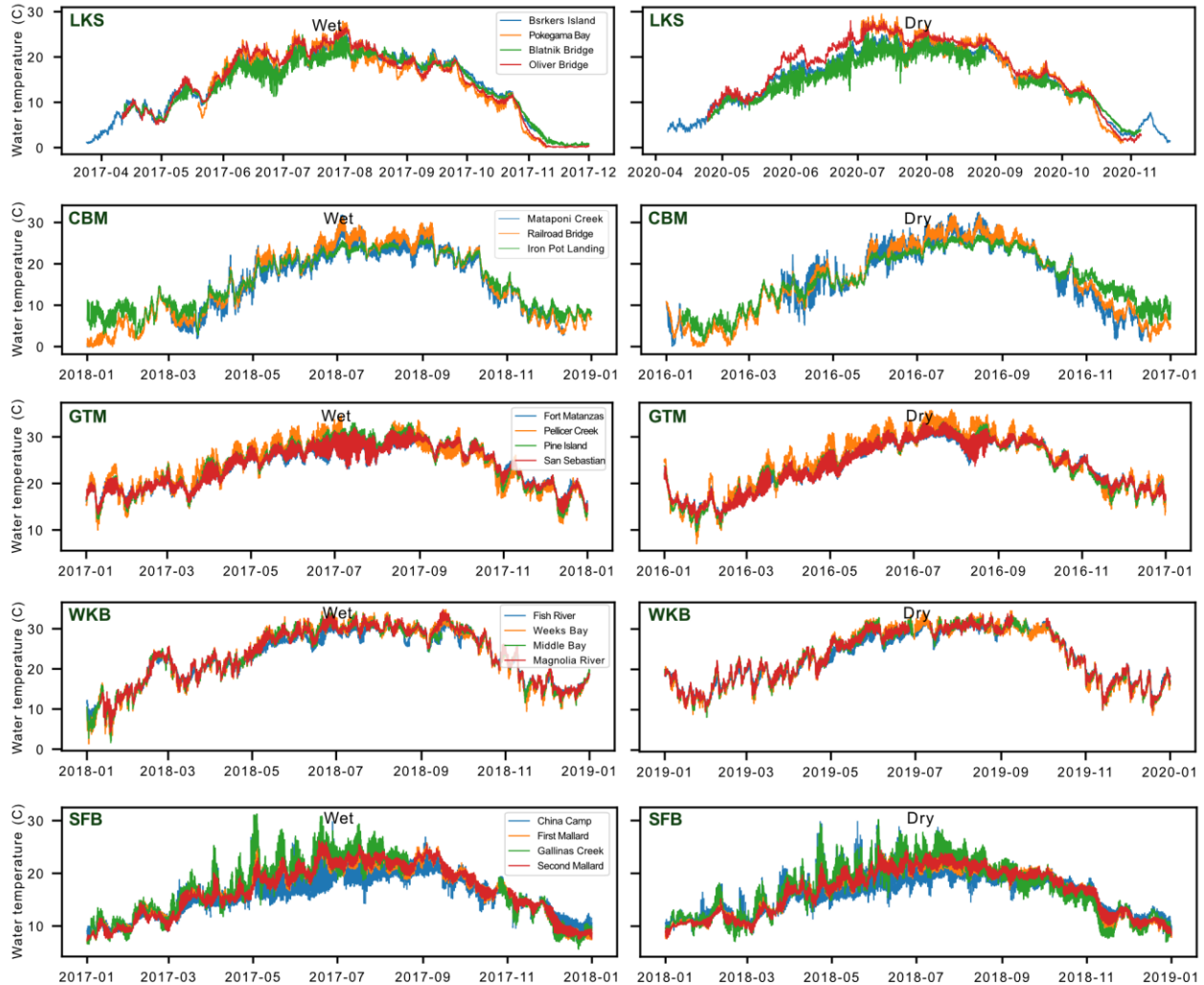


Figure S3: Water temperature during selected wet and dry years for five National Estuarine Research Reserve (NERR) estuaries. Estuary abbreviations: Lake Superior (LKS) NERR, Chesapeake Bay, Maryland (CBM) NERR, Guana Tolomato Matanzas (GTM) NERR, Weeks Bay (WKB) NERR, and San Francisco Bay (SFB) NERR. At LKS NERR, the water temperature record extends from April to December in 2017 and from April to November in 2020, as monitoring is suspended when the St. Louis River freezes over.

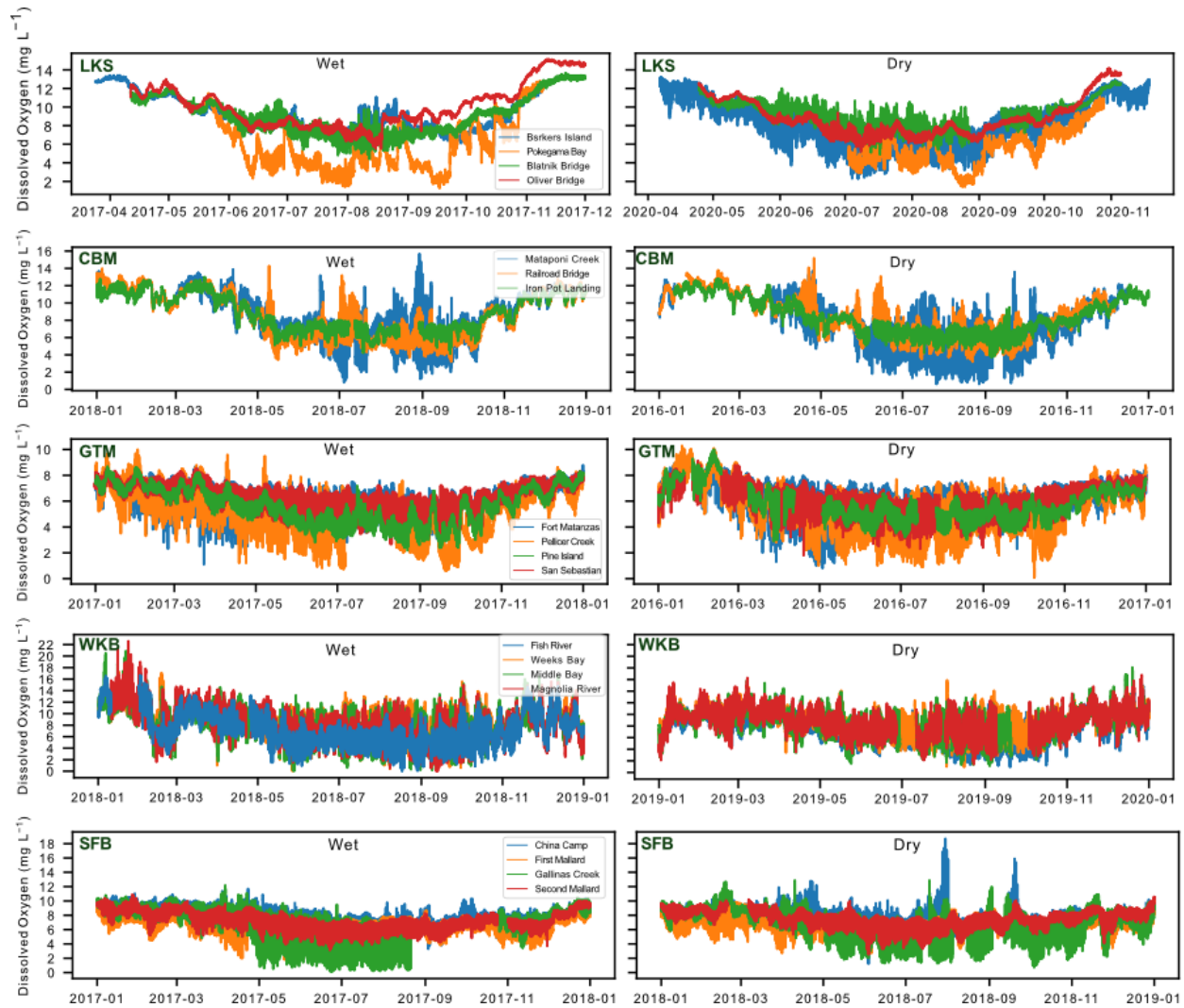


Figure S4: Dissolved oxygen during selected wet and dry years for five National Estuarine Research Reserve (NERR) estuaries. Estuary abbreviations: Lake Superior (LKS) NERR, Chesapeake Bay, Maryland (CBM) NERR, Guana Tolomato Matanzas (GTM) NERR, Weeks Bay (WKB) NERR, and San Francisco Bay (SFB) NERR. At LKS NERR, the dissolved oxygen record extends from April to December in 2017 and from April to November in 2020, as monitoring is suspended when the St. Louis River freezes over.

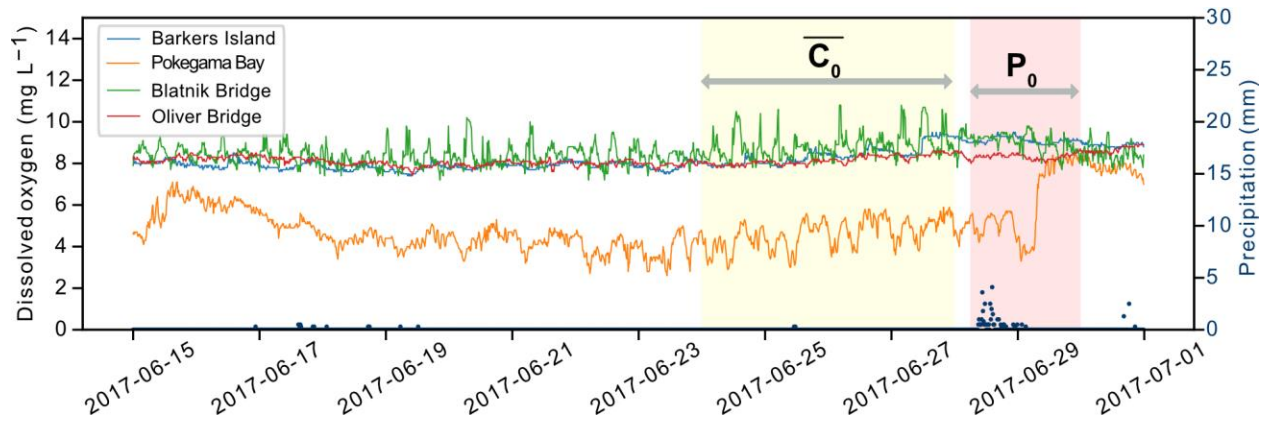


Figure S5: An example for visualizing the selection of variables for resistance index calculations. Dissolved oxygen concentrations (mg L^{-1}) and precipitation (mm) at Lake Superior (LKS) NERR prior to and during a precipitation event on June 28, 2017. The yellow shaded box indicates the time window used to calculate the average pre-precipitation dissolved oxygen concentration (C_0). The red shaded box indicates the time window used to identify the post-precipitation dissolved oxygen concentration (P_0), where P_0 is defined as the maximum displacement from average C_0 .

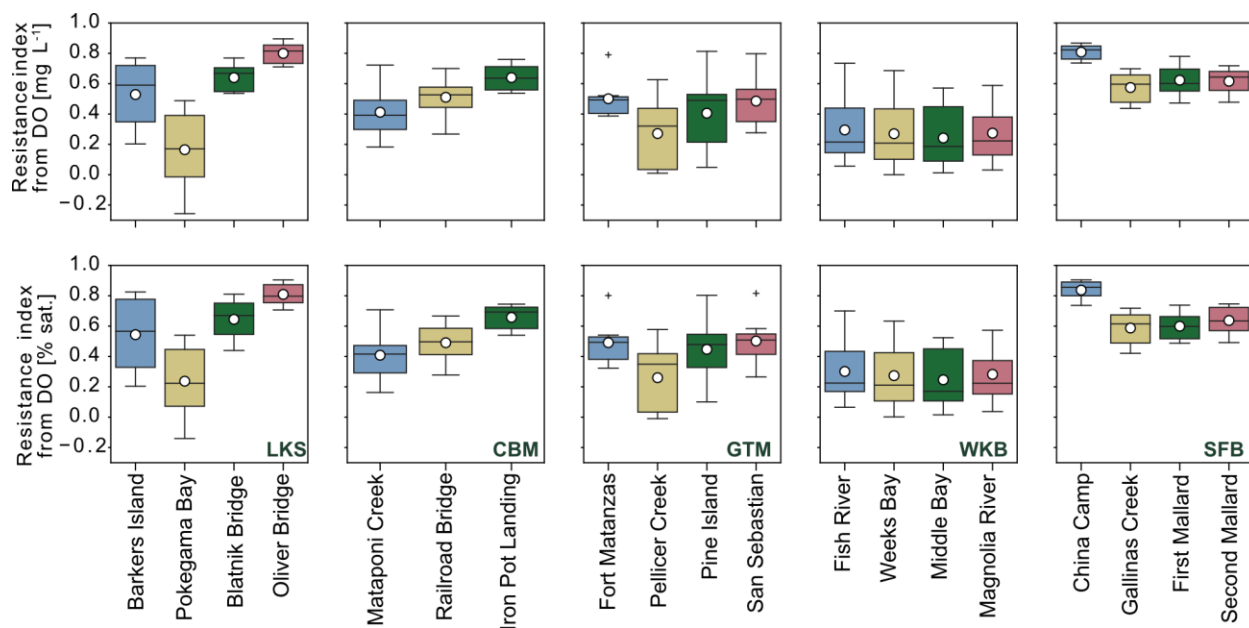


Figure S6: The resistance index at each site calculated using dissolved oxygen (DO) concentration and DO percent saturation. The top row displays the resistance index calculated using DO concentration (mg L⁻¹). The bottom row displays the resistance index calculated using DO percent saturation (% sat.).

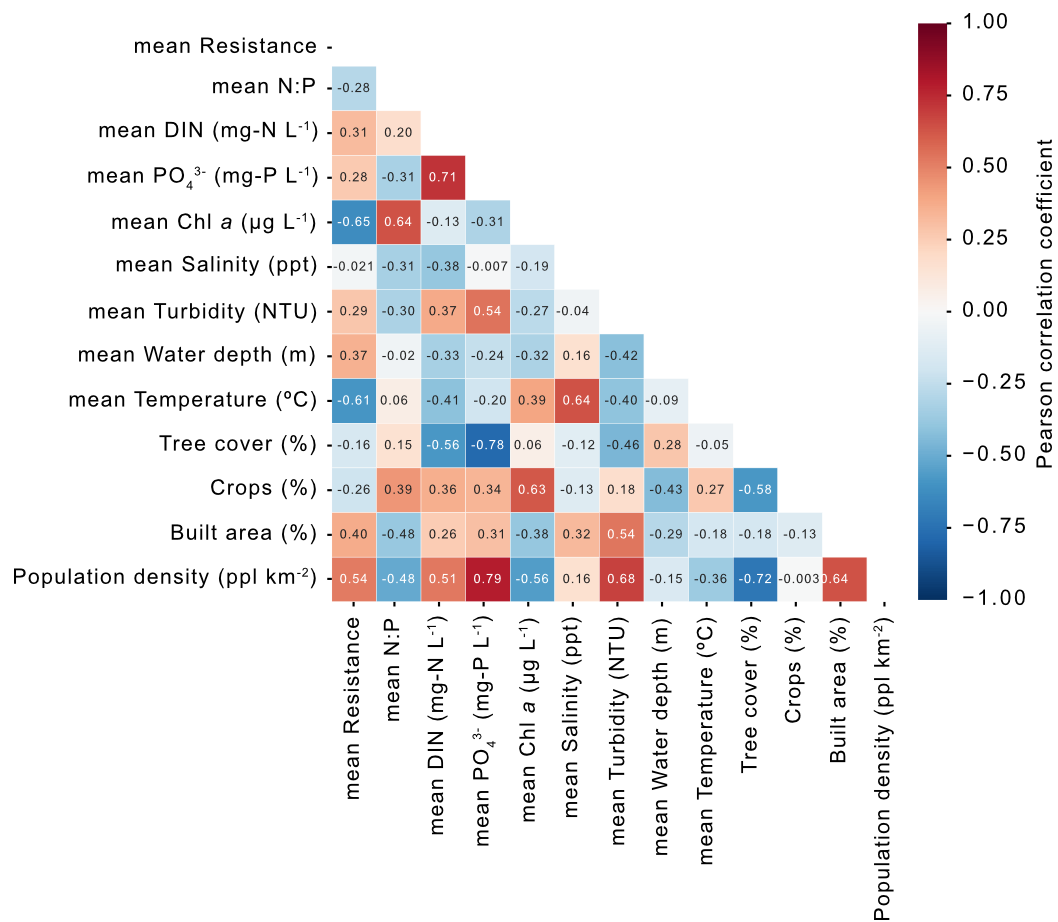


Figure S7: A correlation matrix showing Pearson correlation coefficients (r) for combinations of resistance, water quality, and land use/land cover variables across five estuaries.

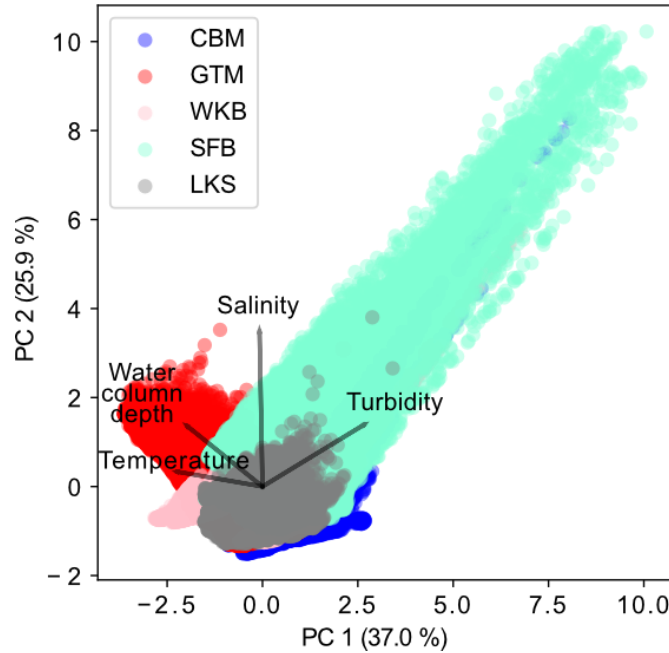
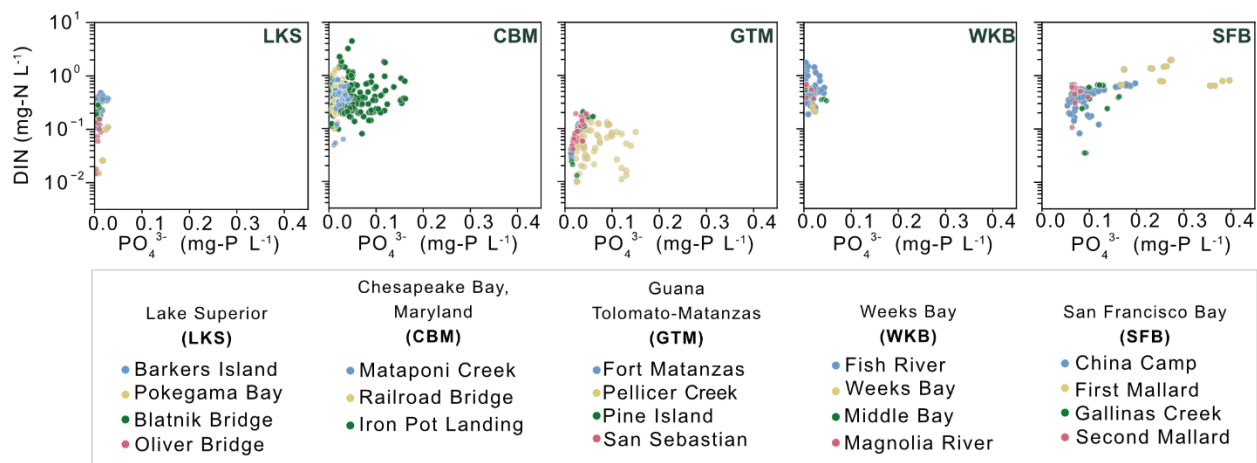


Figure S8: Principal component analysis with Varimax rotation. The analysis includes the Lake Superior (LKS), Chesapeake Bay, Maryland (Jug Bay only) (CBM), Weeks Bay (WKB), San Francisco Bay (SFB), and Guana Tolomato Matanzas (GTM) National Estuarine Research Reserve System estuaries. Variables evaluated as loadings include salinity, turbidity, water temperature, and water column depth. The percentage of variance explained by the first and second principal components (PC1 and PC2, respectively) is shown in parentheses.



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Figure S9: Dissolved inorganic nutrient concentrations at each estuary. Dissolved inorganic nitrogen (DIN) represents the sum of NO₃⁻, NO₂⁻, and NH₄⁺. Note the logarithmic scale on the y-axis. Estuary abbreviations: Lake Superior (LKS) National Estuarine Research Reserve (NERR), Chesapeake Bay, Maryland (CBM) NERR, Guana Tolomato Matanzas (GTM) NERR, Weeks Bay (WKB) NERR, and San Francisco Bay (SFB) NERR. Missing data notes: (1) LKS dry year (2020) ammonium (NH₄⁺) measurements are missing at all monitoring locations; (2) WKB wet year (2018) phosphate (PO₄³⁻) measurements are missing at the Weeks Bay, Middle Bay, and Magnolia River monitoring locations.

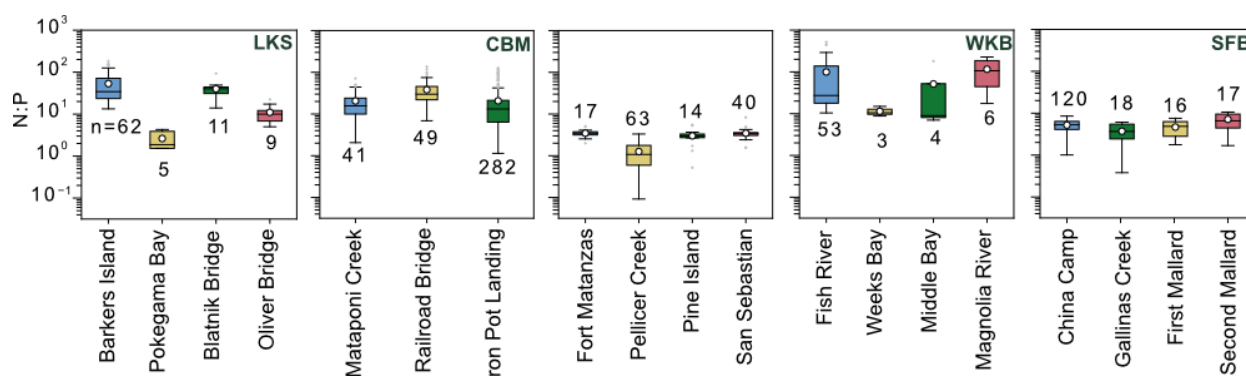


Figure S10: The distribution of the nitrogen-to-phosphorus ratio (N:P) within individual estuaries. Estuary abbreviations: Lake Superior (LKS) NERR, Chesapeake Bay, Maryland (CBM) NERR, Guana Tolomato Matanzas (GTM) NERR, Weeks Bay (WKB) NERR, and San Francisco Bay (SFB) NERR. Means are shown as white circles and medians as solid black lines. Boxes show the quartiles of the dataset, and the whiskers show the rest of the distribution. Note that the y-axis is on a logarithmic scale. The stoichiometric N:P ratio was calculated using dissolved inorganic nitrogen species (i.e., $\text{NO}_3^- + \text{NO}_2^- + \text{NH}_4^+$) and phosphate (PO_4^{3-}). Due to missing PO_4^{3-} measurements during the wet year at the Weeks Bay, Middle Bay, and Magnolia River locations within WKB NERR, the N:P ratios at these locations were calculated only for the dry year.

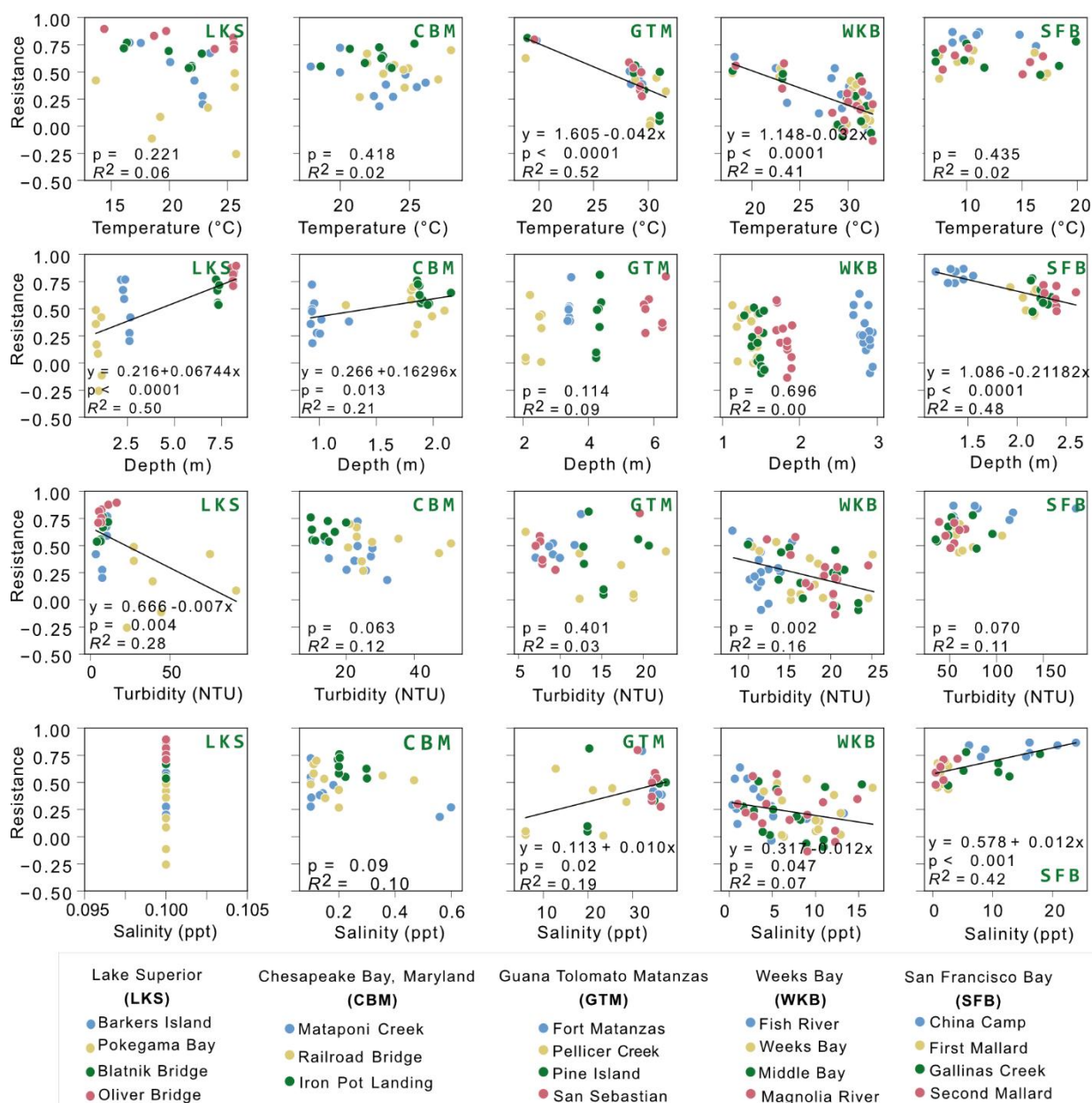


Figure S11: The relationships between resistance and water temperature, water column depth, turbidity, and salinity at each estuary. Estuary abbreviations: Lake Superior (LKS) NERR, Chesapeake Bay, Maryland (CBM) NERR, Guana Tolomato Matanzas (GTM) NERR, Weeks Bay (WKB) NERR, and San Francisco Bay (SFB) NERR. Significant correlations ($p < 0.05$) are shown as black lines. These relationships are based on the mean values of physicochemical factors during the precipitation events used to calculate the resistance index (see dates in Table S3).

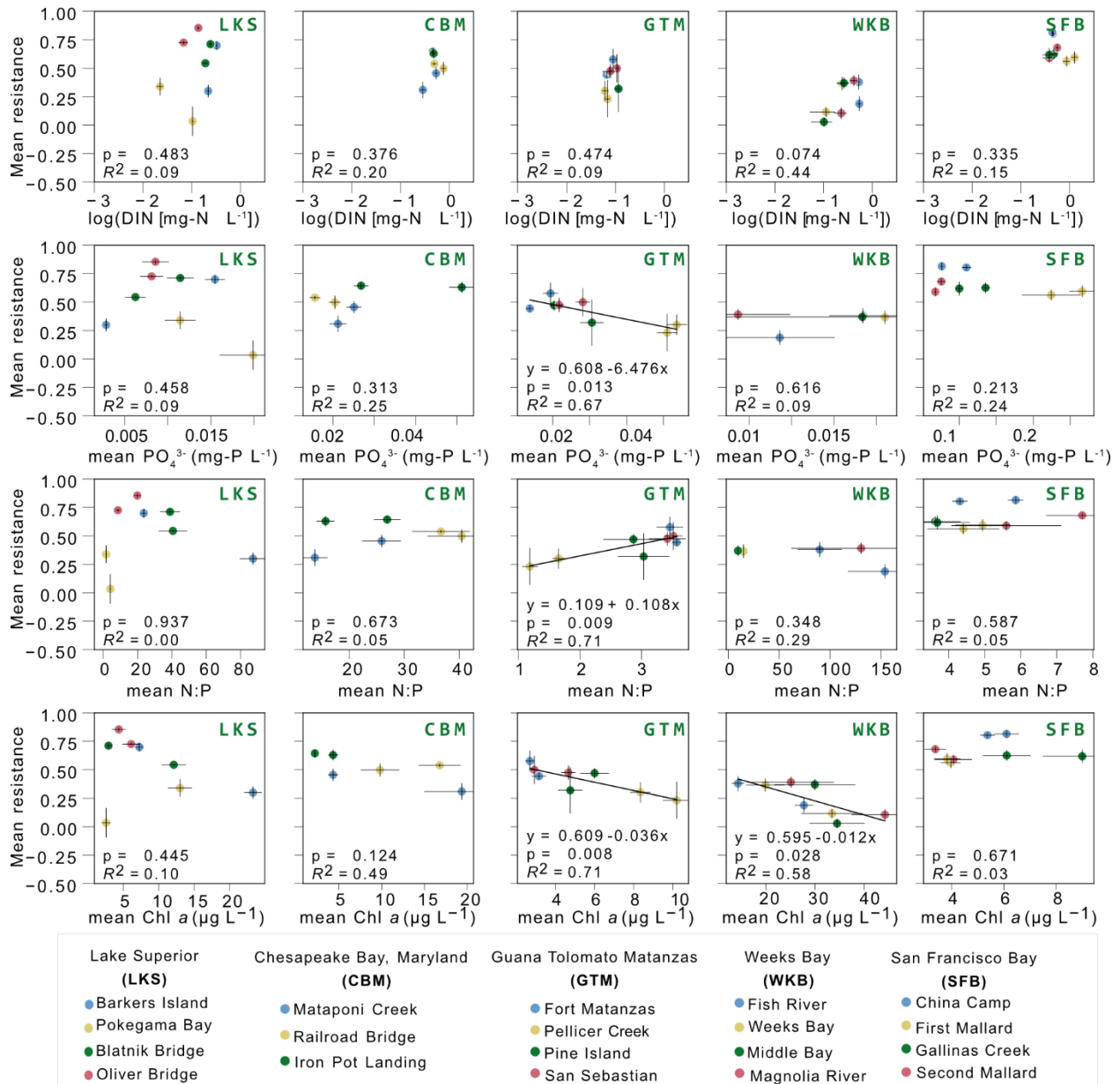
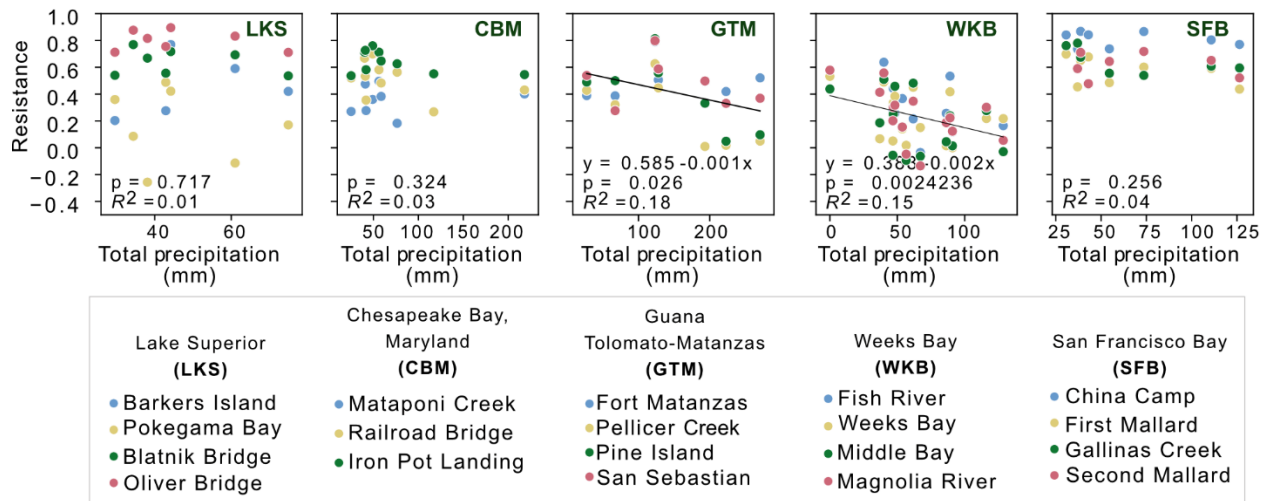


Figure S12: The relationships between resistance and dissolved inorganic nitrogen (DIN), phosphate (PO₄³⁻), N:P, and chlorophyll *a* (Chl *a*) at each estuary. Estuary abbreviations: Lake Superior (LKS) NERR, Chesapeake Bay, Maryland (CBM) NERR, Guana Tolomato Matanzas (GTM) NERR, Weeks Bay (WKB) NERR, and San Francisco Bay (SFB) NERR. Black lines show significant correlations ($p < 0.05$). Standard errors of the mean are indicated by horizontal and vertical black lines. These relationships are based on the annual mean values of resistance, and the annual mean values for nutrient, N:P, and Chl *a* values, which were calculated for wet and dry years separately.



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109 **Figure S13:** The relationships between the resistance index and total precipitation during each
 110 event at each estuary. Estuary abbreviations: Lake Superior (LKS) National Estuarine Research
 111 Reserve (NERR), Chesapeake Bay, Maryland (CBM) NERR, Guana Tolomato Matanzas (GTM)
 112 NERR, Weeks Bay (WKB) NERR, and San Francisco Bay (SFB) NERR. Significant correlations
 113 ($p < 0.05$) are indicated with black lines.

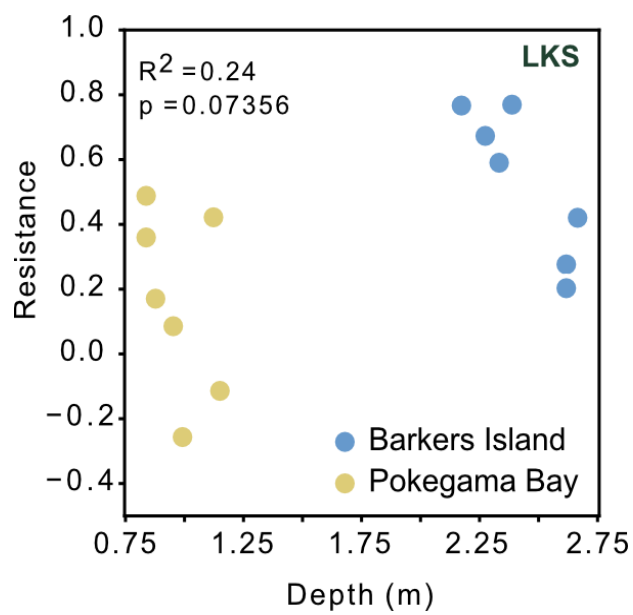


Figure S14: The relationship between resistance and water column depth at the Lake Superior (LKS) NERR, with the Oliver Bridge and Blatnik Bridge locations omitted due to the positioning of the sondes within the water column (see Table S1).

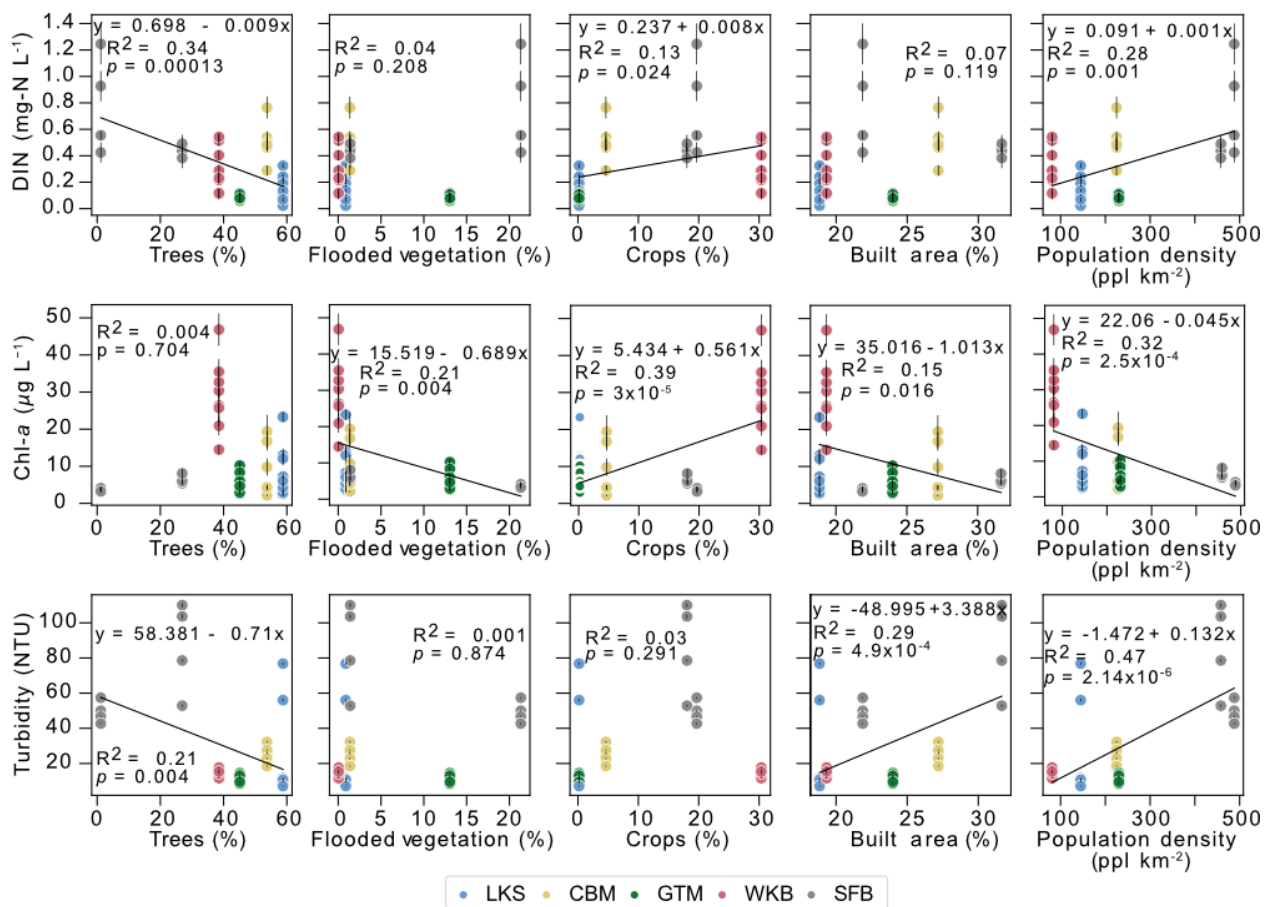


Figure S15: The relationships of dissolved inorganic nitrogen (DIN), chlorophyll *a* (Chl *a*), and turbidity with land use/land cover and population density across five NERR estuaries. Estuary abbreviations: Lake Superior (LKS) NERR, Chesapeake Bay, Maryland (CBM) NERR, Guana Tolomato Matanzas (GTM) NERR, Weeks Bay (WKB) NERR, and San Francisco Bay (SFB) NERR. Regressions for significant relationships ($p < 0.05$) are shown as black lines. All relationships use annual means for physicochemical factors calculated for wet and dry years separately, and land use/land cover characteristics within the 10 km proximity zones associated with the monitoring locations.

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