pH, Salinity, Wind, PAR – Supporting Variables

Question:
How have estuarine pH, salinity, wind speed, wind direction, and photosynthetically active radiation (from sunlight) changed over time in the Great Bay Estuary and Hampton-Seabrook Estuary?

Short Answer
The statistical significance of trends is impacted by the particular duration (start and end points) of the time series. For most of the supporting variables' data, the data collection ends in 2021 and begins in 2003, just as an increase in precipitation was beginning; this period of greater rainfall ended after 2010. Precipitation patterns will impact or correlate with all the variables examined here. In examining these data, it can be enlightening to consider how trends would change if the time series began in either 1990 or 2011, as opposed to a lengthy period of higher than normal precipitation.

The examined period has seen increases in pH, salinity, and photosynthetically active radiation from sunlight (PAR). An increase in pH is contrary to the trend for oceans in New England, but this reflects a broader pattern of well-mixed estuaries seeing increased alkalinity due to minerals being loaded into waters from the watershed. Also, atmospheric pH has increased (gotten less acidic) due to Clean Air Act regulations decreasing acid rain.

Wind speed has increased in April and decreased in September; otherwise, no trends are evident. Wind direction shows no clear pattern with wind coming out of the south-southwest most often; the record also shows some anomalous years in 2012 when the direction shifted to the south and recent years as the wind has shifted to the west.

Why We Track these Variables
pH indicates the concentration of hydrogen ions in water and is impacted by natural processes and human pollution. Estuaries are interesting with regard to pH because oceans have been experiencing decreasing pH levels (more acidic water) while estuarine waters are becoming less acidic due to lower pH in rain and watershed runoff.

Regardless of the causes of fluctuations, pH is important for both animals and plants. Most organisms in estuaries are adapted to a specific range of pH and significant shifts in that range can cause stress. Decreasing pH poses challenges for organisms like clams, blue mussels and lobsters, which require higher pH to build their calcium carbonate skeletons. Regarding eelgrass, some studies have indicated that carbon limitation, especially in high pH and warm water, could be a cause for eelgrass loss.

Salinity in an estuary reflects the mixing of freshwater (salinity = 0 parts per thousand or ppt) and oceanic water (salinity = 33 ppt), with salinity generally trending lower as one proceeds upstream away from the ocean. While some estuarine plants and animals are tolerant of broad swings in salinity, other organisms can be quite sensitive to salinity shifts. Salinity is an important variable for understanding hydrodynamics in estuaries because salt water is heavier than fresh water.

Wind speed and direction impact currents and mixing in estuaries, which in turn impacts indicators such as dissolved oxygen, turbidity, total suspended solids and light attenuation. Therefore, changes in wind can have a significant impact on ecosystem health. In general, wind speed has more of an influence on water quality than wind direction; wind direction becomes more important in estuaries as tidal velocity decreases, such as in the areas in the Great Bay that are far from the channel.

Photosynthetically active radiation (PAR) from sunlight drives photosynthesis in estuaries, which determines how productive an ecosystem is. PAR is not to be confused with light attenuation and turbidity, which are other ways of measuring how light is lost or scattered underwater. Even with increasing PAR, for example, a system could have increased turbidity and reduced light at depth, and reduced light at depth if there are increases in total suspended solids, plankton or colored dissolved organic matter.

Explanation: pH

pH: Data Results

Monitoring in the ocean zone of the Gulf of Maine shows a decreasing trend for pH with most recent values averaging pH 8.1. In Hampton-Seabrook Estuary, the average pH since data collection began in 2018 is 7.8 (Figure pH-1). Despite the short time series, the trend shows a significant decrease.

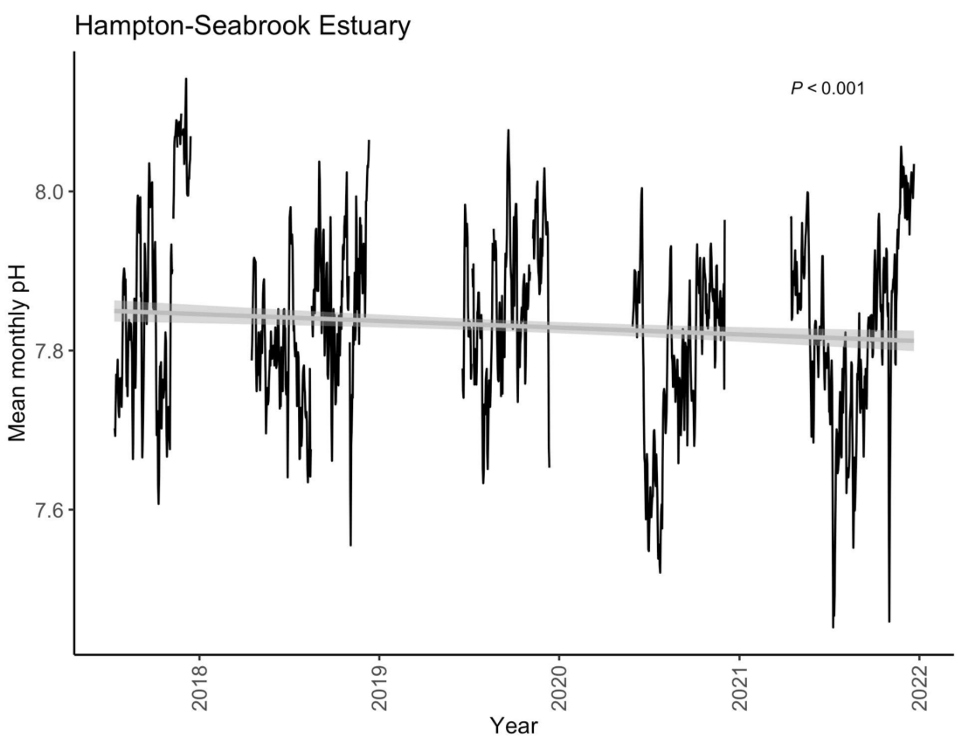

Figure pH-1. pH at the Hampton River station in the Hampton-Seabrook Estuary. Data collection at this station began in 2018. The curve represents the line of best fit with a corresponding 95% confidence level interval for predictions from a linear model.

In the Great Bay Estuary, mean annual pH data collected since 2003 show statistically increasing trends in pH at four sites (Figure pH-2): Great Bay, Lamprey River, Oyster River, and Squamscott River. Three of the sites show recent pH values between pH 7.5 - 8.0, whereas Lamprey River is below pH 7.5. Drilling in by month at two sites (Great Bay and Oyster River, Figure pH-3), we see significant increases over time.

pH: Discussion

In general, pH 6.5 to 8.5 is the optimum healthy range for estuarine organisms. For oysters, pH 6.7 is considered severely acidic and associated with increased mortality. For the American Lobster, between 7.6 - 8.1 is considered a healthy range. In experiments at UNH's Coastal Marine Laboratory, it was found that lobsters reacted to food more slowly when pH was less than 7.5, suggesting their senses were negatively affected by acidified conditions (Gutzler 2019).

Since 2005, pH levels throughout the Great Bay Estuary are higher than 7.5, with the exception of the tidal Lamprey River station. Trends in the Great Bay Estuary show increasing pH levels—at least since 2005—which is the opposite of what is seen in the ocean where pH levels have decreased over the past decades. These data a reflect a broader trend seen throughout estuarine and river systems along the North American East Coast. Many estuaries heavily influenced by land use and watershed processes show an increase in pH and alkalinity. In addition to recovery from acid rain (Kaushai et al. 2013), climate patterns are increasing the amount of minerals washing into the estuary, which in turn increases alkalinity, defined as the ability of a system to resist acidification or reduced pH (Kaushai et al. 2013).

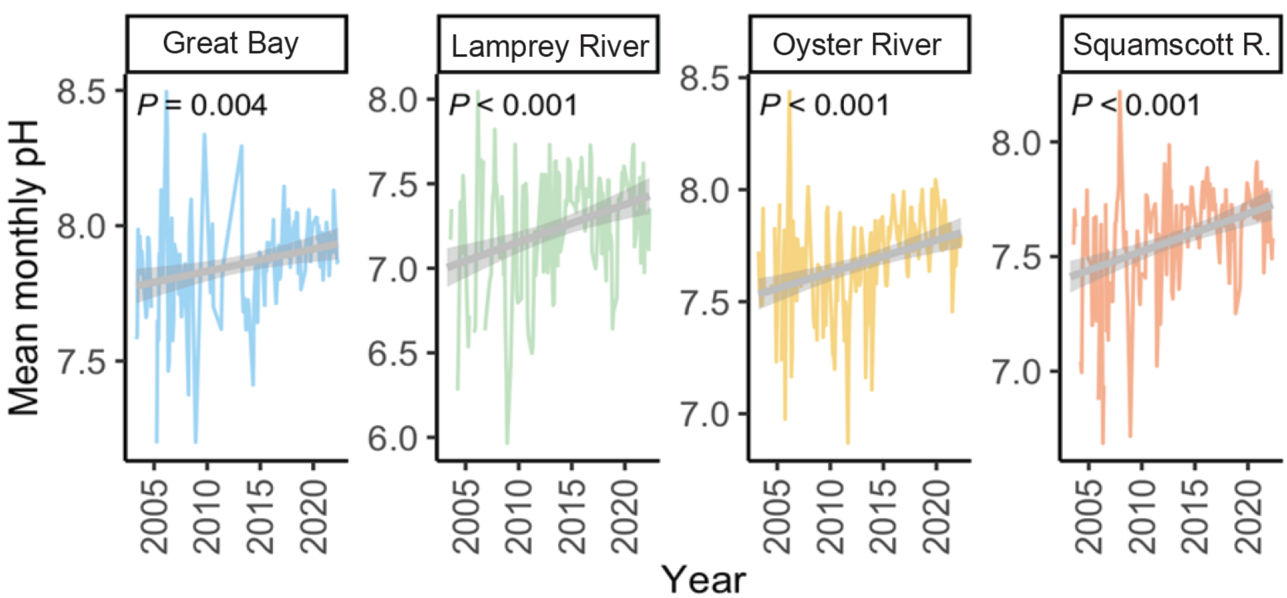

Figure pH-2. Mean monthly pH at four representative sites in the Great Bay Estuary. Each curve represents the line of best fit with a corresponding 95% confidence level interval for predictions from a linear model. Each P value indicates whether the slope of the curve is significantly different from zero.
Data Source: UNH Jackson Estuarine Laboratory.

Ecosystem metabolism also affects pH levels. Increased photosynthesis from more seagrass, plankton or seaweed biomass tends to drive pH up, especially in well-mixed systems like the Great Bay Estuary. When not well-mixed, plant and animal respiration and microbial processing of organic matter can lower dissolved oxygen and pH, especially in bottom waters (Van Dam and Wang 2019). Note that the Lamprey River, less well-mixed than others and often seeing low dissolved oxygen levels, has the lowest pH.

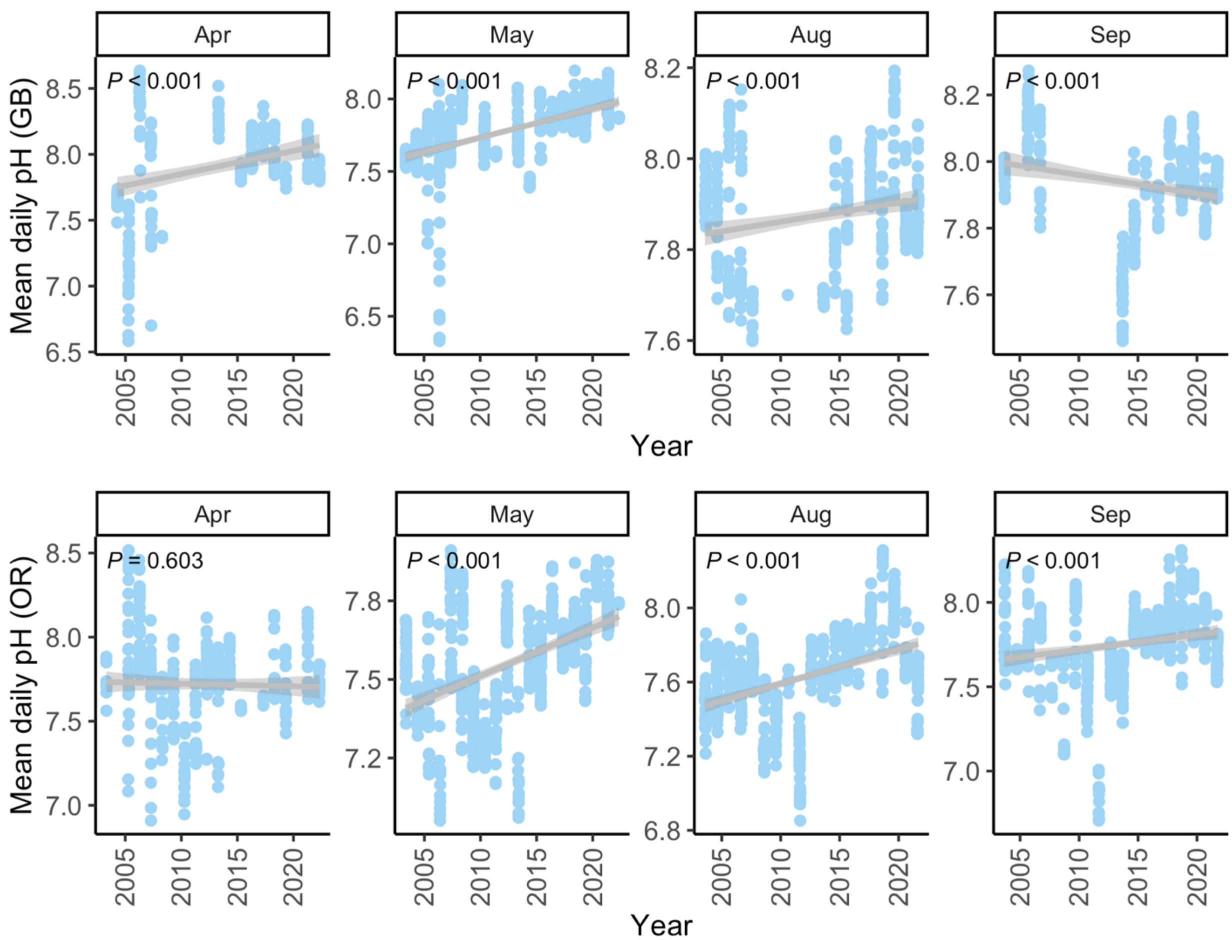

Figure pH-3. Mean daily pH at two representative sites in the Great Bay Estuary: OR = Oyster River and GB = Great Bay, for 4 months spanning the growing season seagrass and seaweed. Each curve represents the line of best fit with a corresponding 95% confidence level interval for predictions from a linear model. Each P value indicates whether the slope of the curve is significantly different from zero.
Data Source: UNH Jackson Estuarine Laboratory.

Explanation: Salinity

Salinity: Data Results/Discussion

At Adams Point, where the time series begins in the late 1980s, the data indicates a decrease in salinity beginning around 2006, with some higher values in recent years (Figure S-1). Notice that until 2006, coincident with a lengthy period of high precipitation and watershed runoff between 2005 and 2010, with a few higher values in recent years (Figure S-1). Prior to 2006, only three data points were lower than 22 ppt whereas after 2006, there are eight instances of annual mean salinity lower than 22 ppt. The other three sites shown in Figure S-1 (from Great Bay, Upper Piscataqua River and Coastal Marine Laboratory) also show a significant increase in salinity for the time series beginning in 2003.

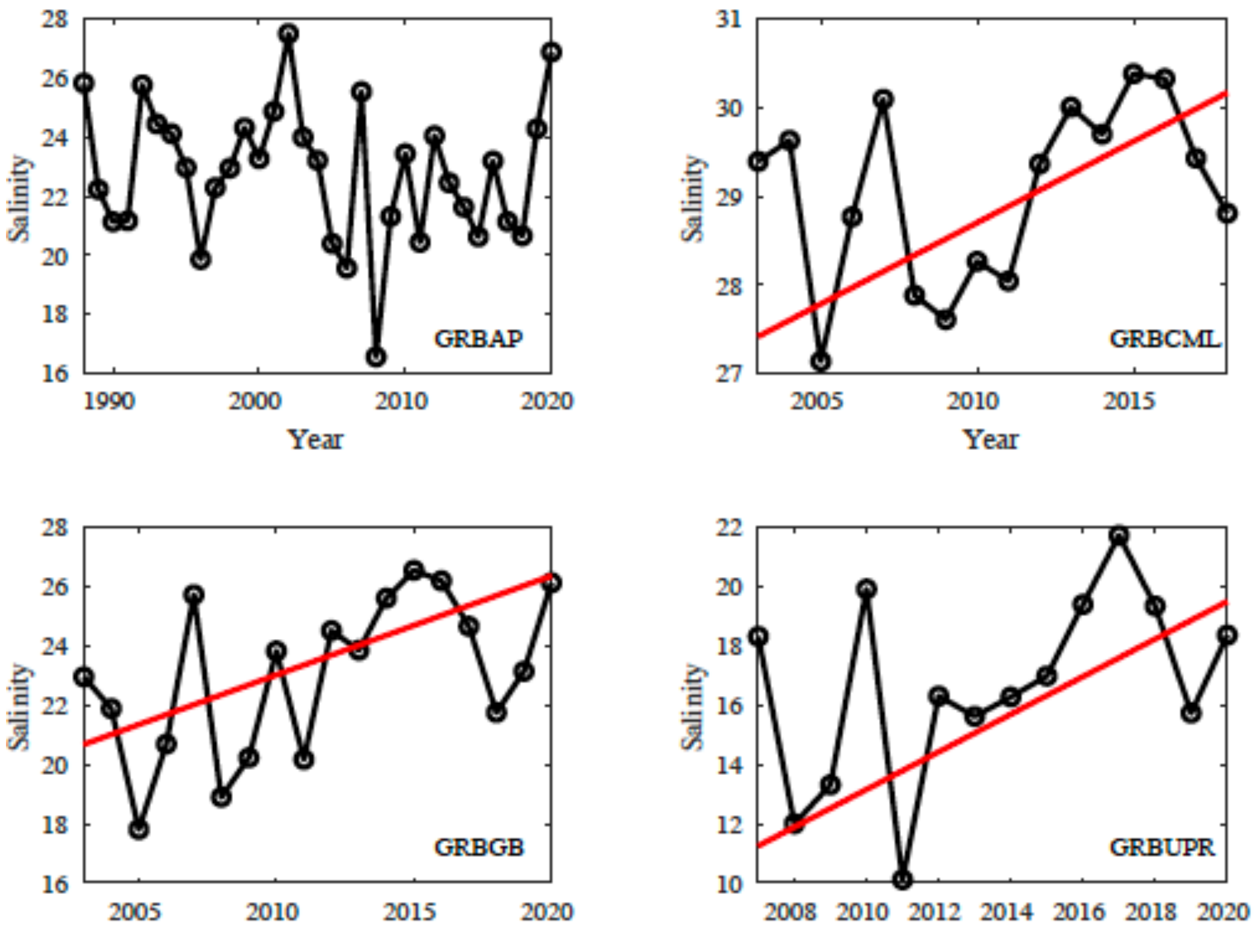

Figure S-1. Annual mean of salinity measured at 4 representative stations in the Great Bay Estuary during sampling that took place on a monthly basis primarily from April to October. GRBCML = Coastal Marine Laboratory at the mouth of Portsmouth Harbor; GRBGB = Great Bay in the middle of Great Bay, south of Adams Point; GRBUPR = Upper Piscataqua River, located between Dover, NH and Eliot, ME north of the General Sullivan Bridge. Trends (p < 0.05) are shown using Kendal-Theil robust lines (red). No trend for GRBAP was detected.
Data Source: UNH Jackson Estuarine Laboratory.

Explanation: Wind Speed

Wind Speed: Data Results/Discussion

Monthly mean wind speed shows no clear trend since 2003 (Figure WS-1). Data analysis on a finer monthly scale, however, Figure WS-2 shows that wind speed in September has decreased significantly over the last 20 years, and wind speed in April has increased, though not significantly so at the *P*<0.05 significance threshold.

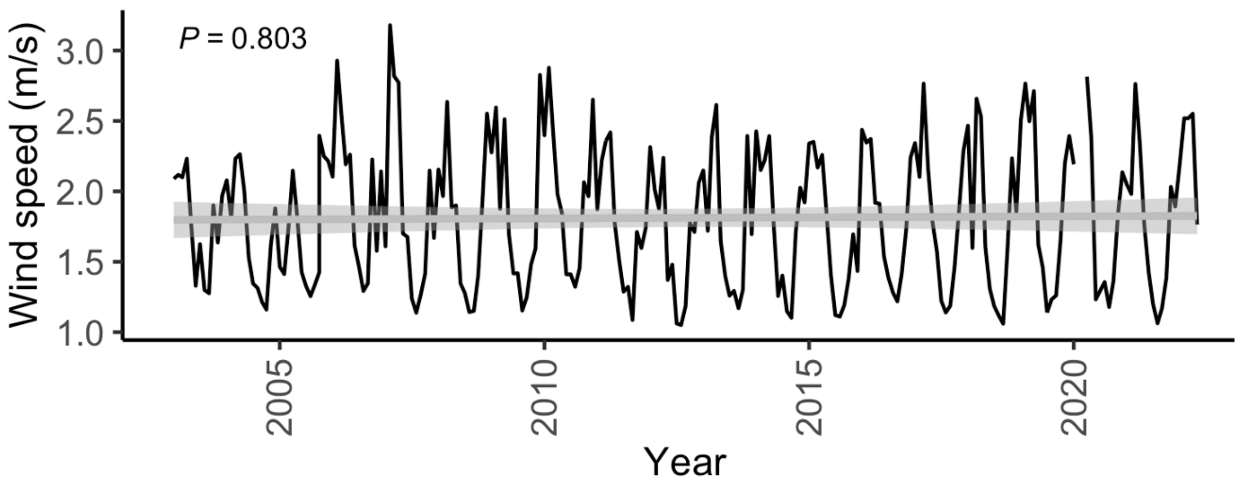

Figure WS-1. Wind speed measured at the Greenland, NH weather station. The curve represents the line of best fit with a corresponding 95% confidence level interval for predictions from a linear model. The P value indicates whether the slope of the curve is significantly different from zero.

Data Source: Centralized Data Management Office, National Estuarine Research Reserve System.

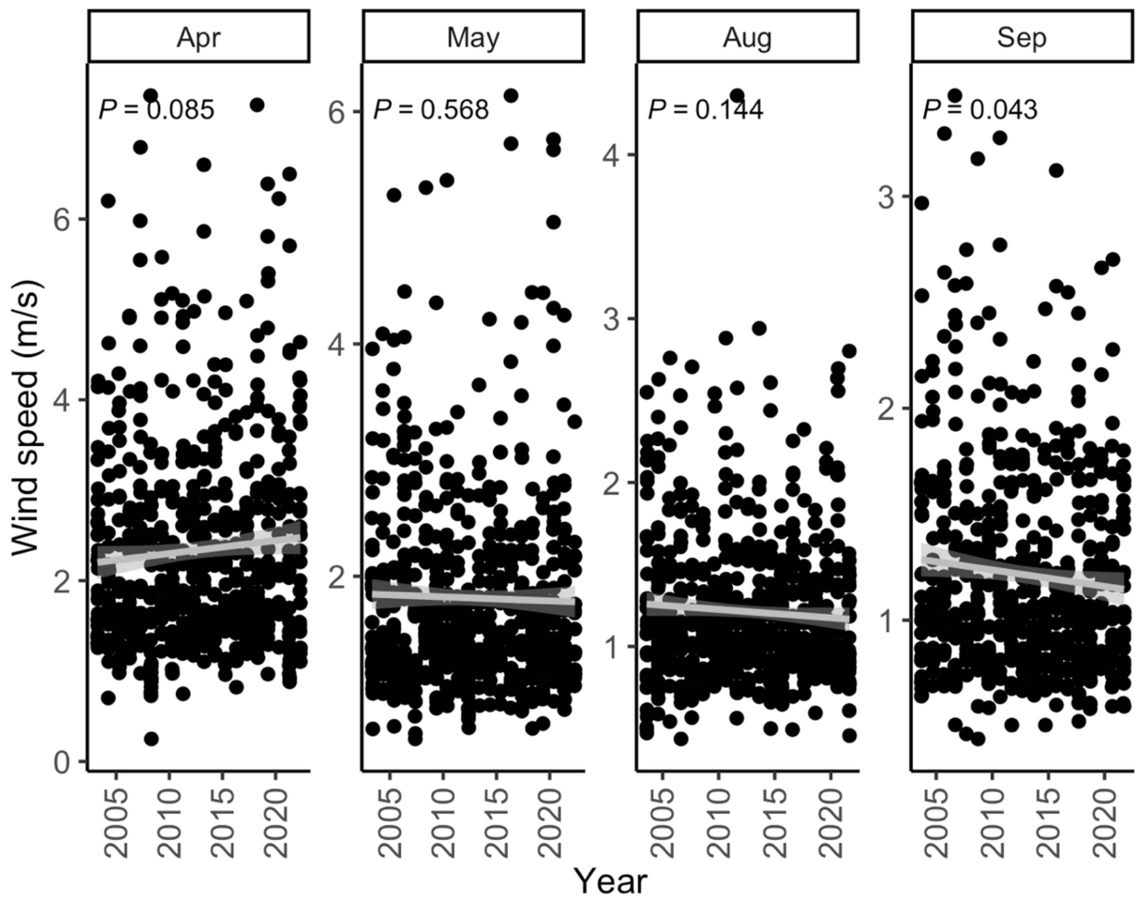

Figure WS-2. Wind speed by month from the Greenland, NH weather station. Each curve represents the line of best fit with a corresponding 95% confidence level interval for predictions from a linear model. Each P value indicates whether the slope of the curve is significantly different from zero.

Data Source: Centralized Data Management Office, National Estuarine Research Reserve System.

Explanation: Wind Direction

Wind Direction: Data Results

Data from the Great Bay meteorological station in Greenland, NH indicate that the dominating wind direction in Spring and Summer—considered the main part of the growing season for seagrass—is between 180 and 200 degrees, corresponding to wind coming out of the south-southwest (Figure WD-1). In recent years, during the spring, wind direction has shifted from the west. It is also notable that between 2011 and 2013 there was a dramatic shift in wind direction when the wind blew primarily from the southeast.

Wind Direction: Discussion

If it were to be observed, a significant change in direction could impact fetch, which in turn could cause significant changes in flow and erosion. Global atmospheric patterns, including the

El Niño and La Niña cycles, impact wind direction and speed. Much more data would be necessary to discern clear trends.

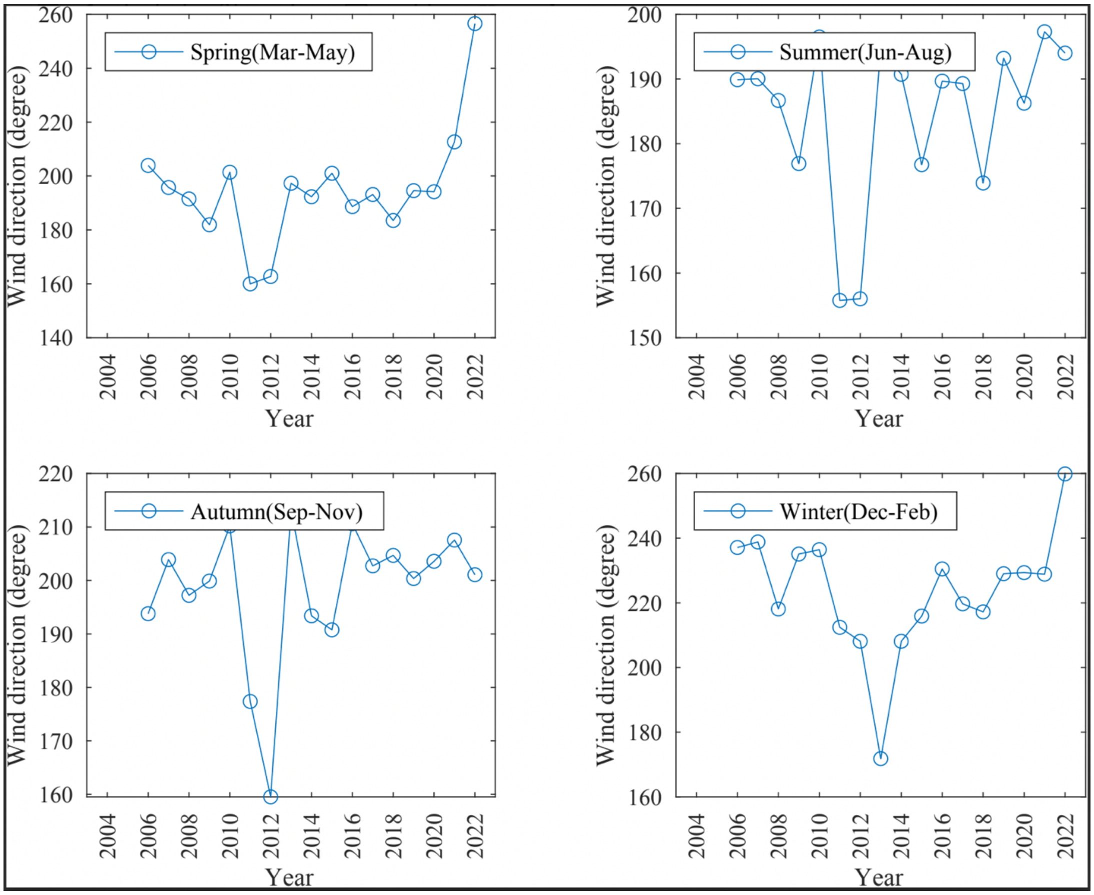

Figure WD-1. Wind direction by season using data collected from the Greenland, NH weather station. The original data with 15-minute intervals within a month were first used for generating monthly mean data. Given that an internannual variability is not necessarily represented by data in a single month, seasonal data with three months were instead calculated. No significant trends were detected.*Data Source: Centralized Data Management Office, National Estuarine Research Reserve System.*

Explanation: Photosynthetically Active Radiation (PAR)

PAR: Data Results/Discussion

Since 2003, monthly mean PAR levels have increased, *albeit* not significantly so (Figure PAR-1). Looking at means on a finer monthly scale, however, shows that PAR in May, August, and September have increased significantly (Figure PAR-2). As for other supporting variables, the increase in PAR over this time period must be examined in the context of when the time series began: in this case, during a time of elevated precipitation levels, which would correspond with more clouds and less sunlight.

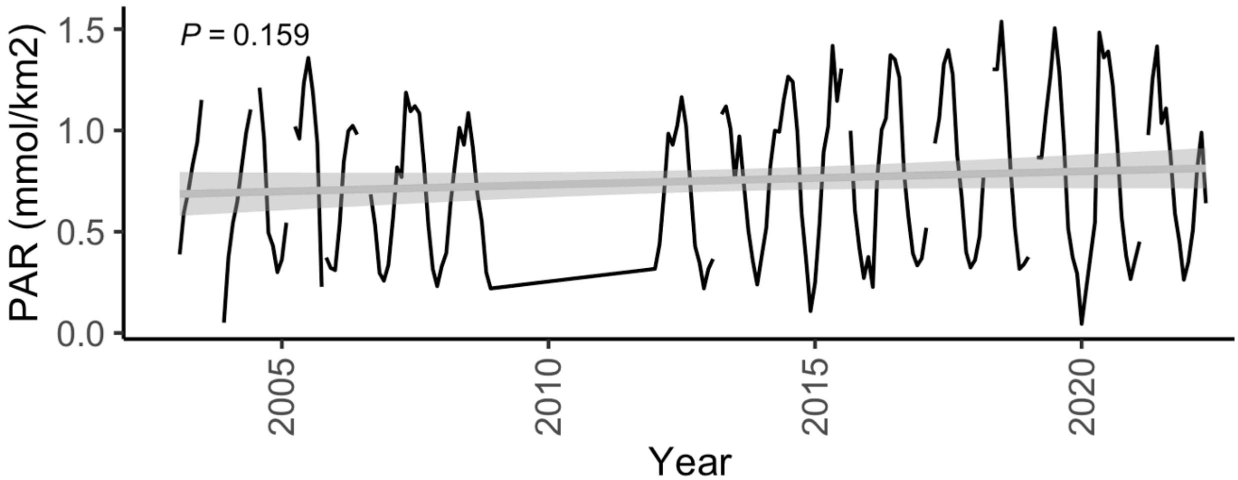

Figure PAR-1. Monthly photosynthetically active radiation (PAR). Data collected from the Greenland, NH weather station. The curve represents the line of best fit with a corresponding 95% confidence level interval for predictions from a linear model. The P value indicates whether the slope of the curve is significantly different from zero.
Data Source: Centralized Data Management Office, National Estuarine Research Reserve System.

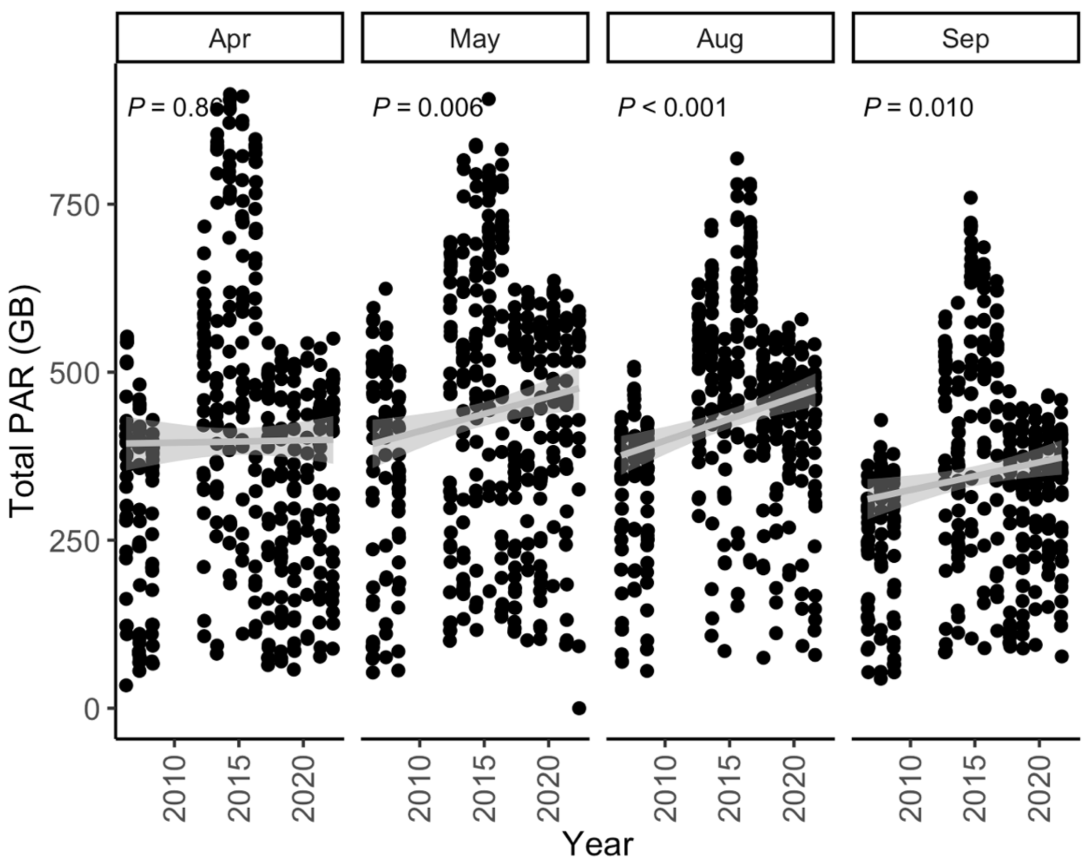

Figure PAR-2. PAR data collected from the Greenland, NH weather station. Each curve represents the line of best fit with a corresponding 95% confidence level interval for predictions from a linear model. Each P value indicates whether the slope of the curve is significantly different from zero.
Data Source: Centralized Data Management Office, National Estuarine Research Reserve System.

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