Increasing Productivity Amid Stable Nutrient Regimes in Rhode Island Lakes and Reservoirs

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Addressing anthropogenic impacts on aquatic ecosystems has long been the focus of lake management. Controlling phosphorus and nitrogen can mitigate the impacts of eutrophication, but to determine its effectiveness requires long-term datasets. A recent analysis of the LAke multi-scaled GeOSpatial and temporal database (LAGOSNE), found stable water quality in the Northeast and Midwestern regions of the United States, however, trends at smaller scales may be masked. We address this by analyzing the University of Rhode Island’s Watershed Watch Volunteer Monitoring Program (URIWW) dataset. URIWW has collected water quality data on Rhode Island lakes and reservoirs for over 25 years. These data, included in LAGOSNE, allow for comparison of water quality trends at regional and state extents. We assess for trends with z-scores (i.e. scaled anomalies) calculated on a per-station basis and examine yearly averages. Temperature and chlorophyll *a* are increasing. Total nitrogen shows a weak increasing trend driven by low years in the early 1990s. Total phosphorus and the nitrogen:phosphorus ratio (N:P) were stable. Applying the site-specific z-score approach to LAGOSNE found similar trends to prior studies with chlorophyll *a*, total nitrogen, total phosphorus, and N:P all stable over time. In short, productivity in Rhode Island lakes and reservoirs is increasing, in spite of stable nutrient regimes. Although not causal, this analysis suggests an association between lake temperature and productivity. Additionally, we demonstrate both the value of long-term monitoring programs, like URIWW, for identifying trends in environmental condition, and the utility of site-specific z-scores for analyzing for long-term trends.

# Introduction

Aquatic ecosystems have been altered as the result of human activities modifying nutrient cycling on a global scale (Vitousek et al. 1997, Filippelli 2008, Finlay et al. 2013). Because of their position in the landscape, lakes can function as integrators and sentinels for these anthropogenic effects (Williamson et al. 2008, Schindler 2009). Increasing nutrient inputs, particularly of N and P, derived from intensive agriculture and densely populated urban areas have contributed to the eutrophication of many lakes (Carpenter et al. 1998, Smith 2003). This eutrophication suggests an increase in the frequency and severity of harmful algal blooms, greater risks for human and animal health, and potential economic costs associated with eutrophic waters (Dodds et al. 2008 , Paerl and Huisman 2009, Kosten et al. 2012, Michalak et al. 2013, Taranu et al. 2015, Brooks et al. 2016). To address these problems, management strategies have historically focused on reducing P inputs to lakes, but research also suggests that reducing N inputs may be more effective in certain situations (Schindler et al. 2008, Paerl et al. 2016). These contrasting studies indicate that spatial differences and relationships between N, P, and chlorophyll *a* exist and that long-term studies are needed to identify trends at local, regional, and national scales.

Programs such as USEPA’s National Lakes Assessment (NLA) provide data that allow for continental scale water quality analysis. These analyses can be used for managing water resources by developing water quality criteria for N, P, and chlorophyll *a* (Herlihy et al. 2013, Yuan et al. 2014). Studying trends across large spatial scales can evaluate the effects of eutrophication such as the degradation of oligotrophic systems as P increases(Stoddard et al. 2016). Broad-scale data can also be used for water quality modeling across a range of spatial scales including for predicting lake trophic state, which is predictive of ecosystem condition (Hollister et al. 2016, Nojavan et al. 2019). These trophic state models indicate that landscape variables (i.e. ecoregion, elevation, and latitude) are important and that regional trends exist. Lake-specific drivers are also important for predicting continental-scale water quality which adds an additional layer of complexity (Read et al. 2015). Despite these challenges, it is important to study at multiple spatial scales because emergent trends on regional or continental scales may not be evident when studying individual lakes (Cheruvelil et al. 2013, Lottig et al. 2014).

Previous studies using regional data from the northeastern and midwestern United States have investigated spatial and temporal water quality trends and have shown differences based on scale. Macro-scale (i.e. subcontinental) drivers of water quality trends are complex and may vary temporally (Lottig et al. 2017). This complexity can cause nutrient (N and P) trends to have different drivers than ratios of the individual nutrients (Collins et al. 2017). On a regional scale, trends of N, P, and chlorophyll *a* differ as factors such as land use and climate vary among regions, particularly when comparing the northeastern and midwestern US (Filstrup et al. 2014, 2018). Thus, it was surprising when stasis was reported over a 25 year period for these regions (Oliver et al. 2017). Given what is known about long term trends in water quality within the broader region of the northeastern United States, we were curious if those trends were also present in water quality trends in Rhode Island lakes and reservoirs.

Examining long term trends in Rhode Island lakes is possible because of the data gathered by University of Rhode Island’s Watershed Watch (URIWW). URI’s Watershed Watch is a citizen science project founded in the late 1980’s that has built a robust collaboration between URI scientists and a vast network of non-expert volunteer monitors. Volunteer monitors are trained and then collect *in situ* data as well as whole water samples during the growing season. These efforts have been ongoing in some waterbodies since 1988. These types of citizen science efforts allow for the collection of reliable data that in turn lead to crucial and frequently unexpected insights (Dickinson et al. 2012, Kosmala et al. 2016). Additionally, the fact that volunteer monitors are used has allowed for this program to persist much longer than agency run programs that are often prone to uncertain funding. Here specifically, URIWW data contributed to not only the larger regional study by Oliver et al. (Oliver et al. 2017), but also allowed us to examine the long-term trends in Rhode Island.

Thus, the goals of this study were to look at approximately 25 years of lake and reservoir data in Rhode Island and answer two questions. First, what are the state-wide trends in total nitrogen, total phosphorus, nitrogen to phosphorus ratio (N:P), chlorophyll *a*, and lake temperature. Second, are water quality trends in Rhode Island similar to regional trends in the northeastern United states. Another focus of this paper was to apply existing methodologies for examining long term climate records (e.g., (Jones and Hulme 1996)) to water quality data in order to examine long term trends. Lastly, this analysis has also been done using open data from the URI Watershed Watch program and the LAGOS project and the analysis in its entirety is available for independent reproduction at <https://github.com/usepa/ri_wq_trends> (Soranno et al. 2017, Stachelek and Oliver 2017).

# Methods

For this study we combined a long-term dataset on water quality of lakes in Rhode Island, with a trend analysis based on centered and scaled water quality values (i.e. z-scores) to find increasing or decreasing annual water quality trends. Details are outlined below.

## Study Area and Data

The study area for this analysis includes data from lakes and reservoirs in the state of Rhode Island that were collected by the University of Rhode Island’s Watershed Watch (URIWW) program (Figure 1). The URIWW is a volunteer monitoring program that has been collecting water quality data from Rhode Island lakes and reservoirs for over 25 years. The program began in 1988, monitoring 14 lakes and has now grown to include over 250 monitoring sites on over 120 waterbodies, including rivers/streams, and estuaries, with more than 400 trained volunteers. URI WW now provides more than 90% of Rhode Island’s lake multi-year baseline data, and is an integral part of the state’s environmental data collection strategy. Data QA/QC is of paramount importance; volunteers are trained both in the classroom and the field, and are provided with all the necessary equipment and supplies, along with scheduled collection dates. For freshwater lakes and reservoirs, weekly secchi depth and water temperature are recorded, along with bi-weekly chlorophyll *a* and dissolved oxygen. Water samples are collected three times per season (May through October) to be analyzed in the EPA-certified laboratory.

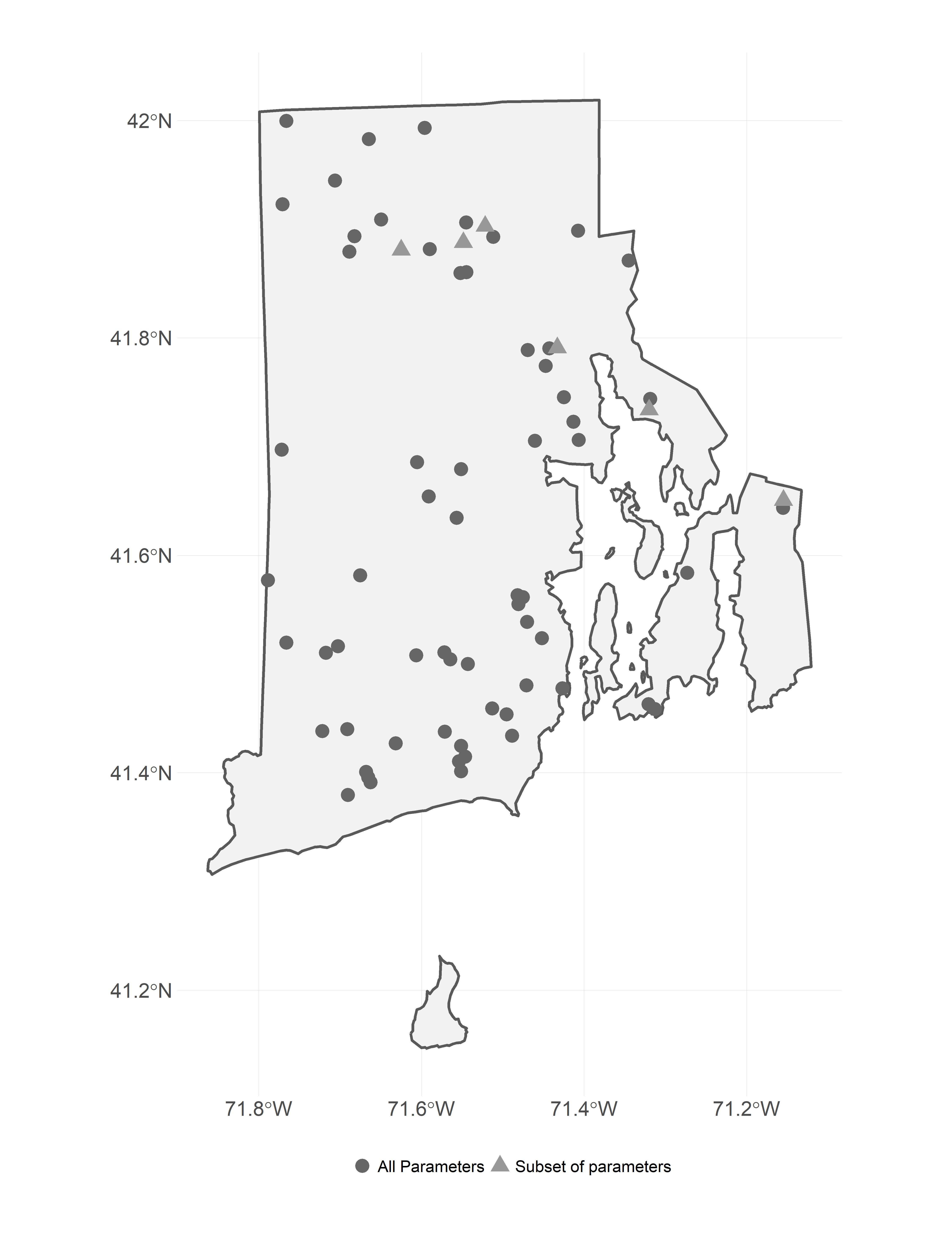


Figure 1: Map of URI Watershed Watch lake and reservoir sampling sites

In particular we selected URIWW data that matched the following criteria: 1) were sampled between 1990 and 2016, 2) were sampled in May to October, 3) and were sampled at a depth of 2 meters or less. For this analysis we were interested in trends in lake temperature, total nitrogen, total phosphorus, N:P, and chlorophyll *a*. For each of these parameters we further filtered the data to select sites that had at least 10 years of data for a given parameter. The final dataset used in our analysis included 69 lakes and reservoirs which had approximately 67 samples for temperature, 67 samples for chlorophyll *a*, 65 samples for Total Nitrogen (TN), 66 samples for Total Phosphorus (TP). Of the 69 sampling sites, 63 had data for all 5 parameters.

Additionally, prior studies have looked at water quality trends across a larger region of the Northeastern United states that included 17 states including Minnesota, Wisconsin, Iowa, Missouri, Illinois, Indiana, Michigan, Ohio, Pennsylvania, New York, New Jersey, Connecticut, Massachusetts, Rhode Island, Vermont, New Hampshire, and Maine (Soranno et al. 2015, Oliver et al. 2017). The authors found little change in water quality trends across this region (Oliver et al. 2017) . We repeated our analysis (see **Water Quality Trend Analysis** section) with the same dataset used by (Oliver et al. 2017), the LAGOSNE dataset (Soranno et al. 2015, 2017, Stachelek and Oliver 2017). Temperature data were not available, thus we only examine trends, using our analytical methods, for total nitrogen, total phosphorus, N:P, and chlorophyll *a* from the LAGOSNE database.

## Water Quality Trend Analysis

There are many different methods for analyzing time series data for trends. One of the difficulties that is encountered when you have multiple sampling locations is how to identify a trend when you have variation at the scale of the sampling location as well as variation in when a sampling location might have been added to a dataset. For instance, if you have long-term data on water quality for several waterbodies, yet the cleaner waterbodies were sampled more frequently in early years then a simple comparison of raw-values over time might show a decrease in water quality. Thus, it is necessary to account for this type of site-specific variation. This is similar to how the long-term temperature trends are analyzed using temperature anomalies (e.g., (Jones and Hulme 1996)). The general approach is to calculate site-specific deviations from a long-term mean over pre-determined reference period. This allows all sites to be shifted to a common base line and the deviations, or anomalies, show change relative to the reference period.

### Z-score

Anomalies are very useful and informed the approach we chose to follow. However, using anomalies works best with a single measure (e.g temperature) or with multiple measurements that are on the same scale. The water quality parameters that we explored have different scales and thus the anomaly alone is difficult to interpret across metrics. For instance, temperature in Rhode Island lakes during the growing season will range from approximately 15 degrees Celsius to a high of 30 degrees Celsius, whereas phosphorus might range from near zero ug/l to ~900 ug/l. To standardize these values we used the common approach of dividing each anomaly by the standard deviation for the reference period (e.g., (Jones and Hulme 1996)). The resultant value is commonly referred to as a z-score. We use these z-scores to examine each water quality variable for a trend over the time period of 1993 to 2016. Furthermore, since we are interested in water quality trends over time, we wanted to explore how each site was responding. Thus, our z-scores were calculated over the reference period, 1993-2016, for each site. We refer to this approach as the site-specific z-scores

### Summarizing site-specific z-scores

Details for our approach of calculating the site-specific z-scores and the yearly averages are as follows and are presented graphically in Figure 2. Additionally, an example R script, schematic.R and example dataset, schematic.csv to recreate and demonstrate the calculations in Figure 2 is available from (**???**).

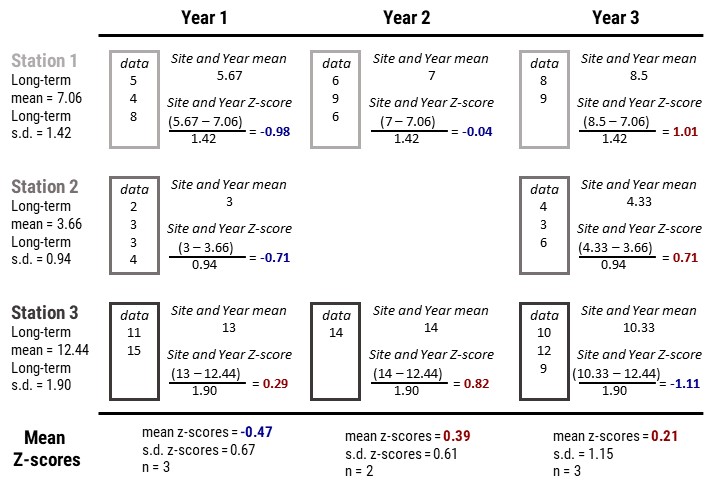


Figure 2: Example calculation of the site-specific z-scores and yearly mean z-scores.

The general steps, outlined in Figure 2 and listed below, are repeated for each of the water quality parameters.

1. For each site, calculate the per site and per year mean values which results in a single mean value for each site and year. This step prevent bias from pseudoreplication of multiple measurements of the same site in a given year (Hurlbert 1984). The per site means across years are assumed to be independent.
2. Calculate the long-term reference mean and reference standard deviation for all per site and per year means. This results in a single long-term mean and standard deviation for each of the sites.
3. Calculate the z-score for each per site and per year mean by subtracting the reference mean and dividing by the reference standard deviation.
4. Summarize the per site and per year z-scores by calculating the mean z-score per year. The resultant values are analyzed for a trend over time.

### Linear regression on yearly means

Testing for a regression slope being different than zero can be used to test for monotonic trends in water quality data (Helsel and Hirsch 2002). We used these standard procedures to test for positive or negative trends in lake temperature, chlorophyll *a*, total nitrogen, and total phosphorus. For each parameter we fit a regression line to the z scores as a function of year and tested the null hypothesis that no trend existed (e.g. 1 = 0).

### Comparison of Rhode Island to the Region

Prior studies have shown relatively stable water quality in the lakes of the Northeastern United Sates (Oliver et al. 2017). While the University of Rhode Island’s Watershed Watch data were included in that regional study, we were curious if regional trends were masking local scale trends in Rhode Island and thus, wanted to compare the trends at the regional scale to the trends at the state scale. The analysis conducted by Oliver et al. (2017) is a robust approach; however, to make direct comparisons between Rhode Island and the region, we re-analyzed the same dataset used by Oliver et al. (2017) but using the trend analysis approach outlined above.

# Results

During the sampling period of 1990 to 2016 Rhode Island lakes and reservoirs average lake temperature was 21.93 celsius, average total nitrogen was 606.56 µg/l, average total phosphorus was 24.44 µg/l, average N:P ratio was 41.56 , and average chlorophyll was 10.13 µg/l (Table 1).

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Parameter | Units | 25th Percentile | Mean | Median | 75th Percentile | Max | Std. Dev |
| temp | celsius | 21.07 | 21.93 | 22.20 | 23.08 | 29.00 | 1.88 |
| total\_n | µg/l | 364.38 | 606.56 | 475.00 | 703.33 | 10742.50 | 494.98 |
| total\_p | µg/l | 10.50 | 24.44 | 15.00 | 24.00 | 664.00 | 33.74 |
| np\_ratio |  | 24.35 | 41.56 | 32.50 | 43.09 | 1063.74 | 46.28 |
| chla | µg/l | 2.21 | 10.13 | 4.51 | 10.47 | 666.23 | 22.07 |

*Table 1: Summary statistics for URI Watershed Watch data from 1990 to 2016.*

For lakes and reservoirs in the larger region represented by the LAGOSNE States, average total nitrogen was 854.14 µg/l, average total phosphorus was 31.66 µg/l, average N:P ratio was 40.89 , and average chlorophyll was 16.8 µg/l (Table 2).

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Parameter | Units | 25th Percentile | Mean | Median | 75th Percentile | Max | Std. Dev |
| total\_n | µg/l | 346.00 | 854.14 | 560.00 | 923.33 | 16778 | 1205.11 |
| total\_p | µg/l | 9.50 | 31.66 | 15.50 | 30.00 | 1200 | 53.70 |
| np\_ratio |  | 18.12 | 40.89 | 26.78 | 39.60 | 40033 | 465.77 |
| chla | µg/l | 3.20 | 16.80 | 6.20 | 17.22 | 696 | 30.35 |

*Table 2: Summary statistics for LAGOSNE data from 1990 to 2016.*

## State-wide trends in water quality

Average yearly scaled temperature in lakes and reservoirs appear to be increasing (slope: 0.038 , p-value: 0.00755) with the large majority of years with average temperature greater than the long term average occurring in the years since 2000 (Figure 3). Chlorophyll *a* is also showing an increasing trend over time (slope: 0.058 , p-value: 0) and with the exception of a slightly above average year in 2003, the above average years have all occurred since 2010 (Figure 4A.).

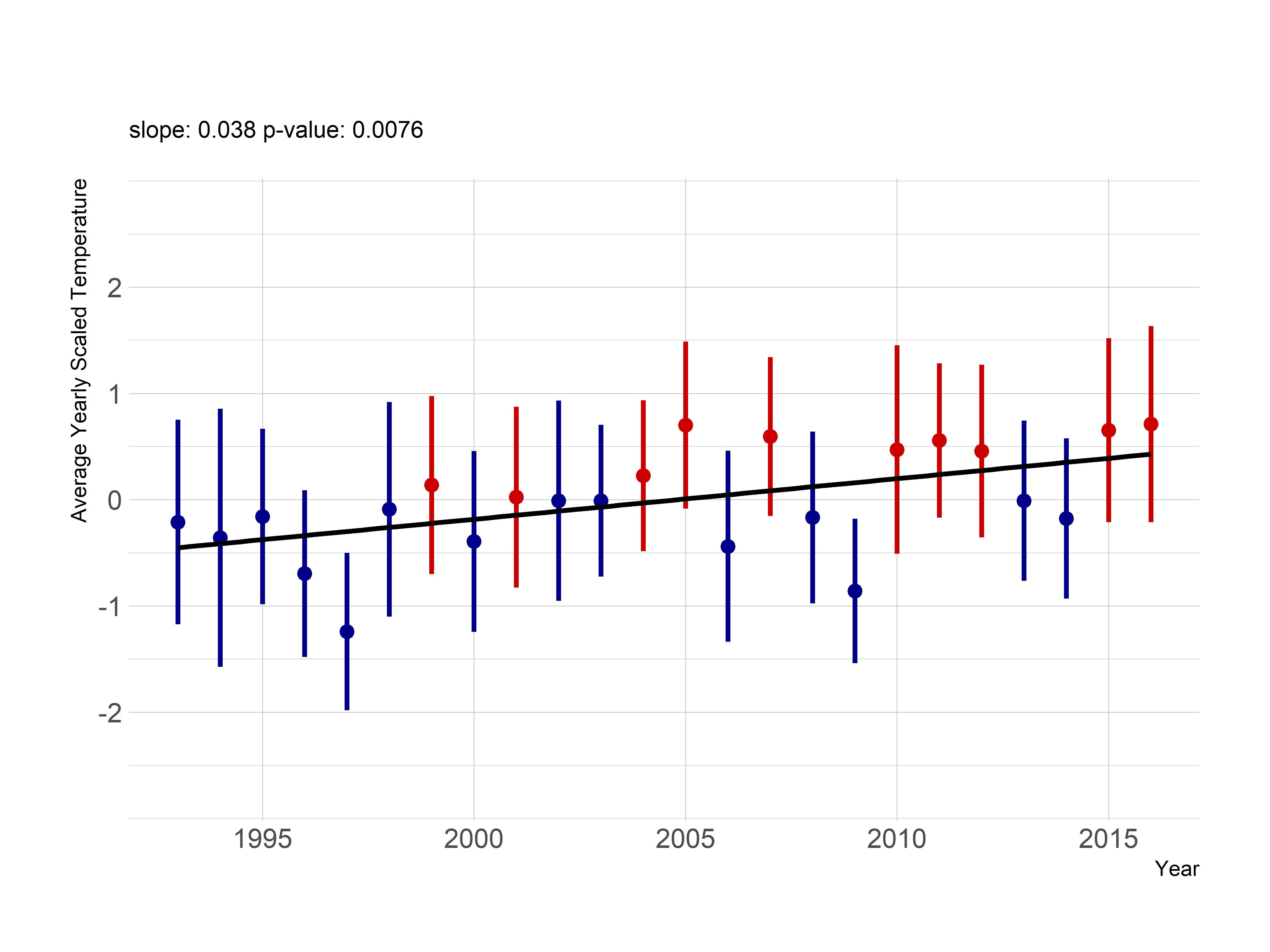


Figure 3: Yearly trend over 20+ years of lake temperature in Rhode Island lakes and reservoirs. Points are averages and ranges are standard deviations with blue indicating an average below the long term mean and red indicating an average above the long term mean.

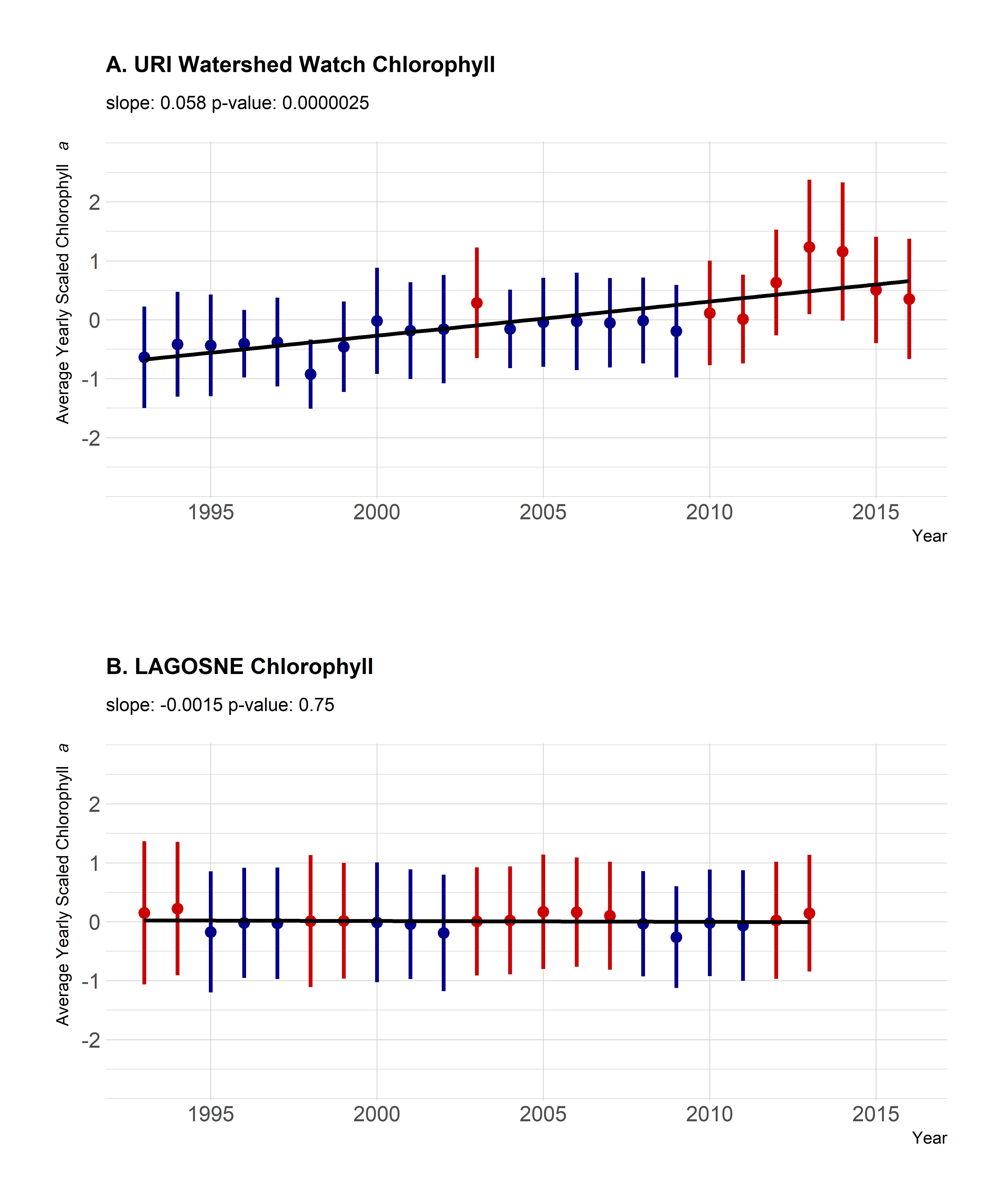


Figure 4: Yearly trend over 20+ years of chlorphyll \*a\* (average z-score). Panel A. shows yearly averaged chlorophyll \*a\* z-scores from the URI Watershed Watch data. Panel B. shows yearly averaged chlorophyll \*a\* z-scores from the LAGOSNE dataset. Points are averages and ranges are standard deviations with blue indicating an average below the long term mean and red indicating an average above the long term mean.

Average yearly trends for nutrients showed weaker or no trends over time. Total nitrogen did suggest a positive trend (slope: 0.023 , p-value: 0.00148); however, that trend is driven by the lower than average total nitrogen values in 1993 and 1994 (Figure 5A.). Since 1995, the yearly trend is shows much lower increase over time (slope: 0.011, p-value: 0.04177). Total phosphorus does not show a trend over time in the yearly scaled values (slope: 0.023 , p-value: 0.00148) and years that are over or under the average are evenly distributed over the years (Figure 6A.). The pattern is the same for the N:P ratio (slope: 0.012, p-value: 0.278) with little evidence suggesting a change in the concentrations of total nitrogen relative to the concentration of total phosphorus (Figure 7A.). Data for all figures are available as a comma-separated values file, yearly\_average\_z.csv from (**???**).

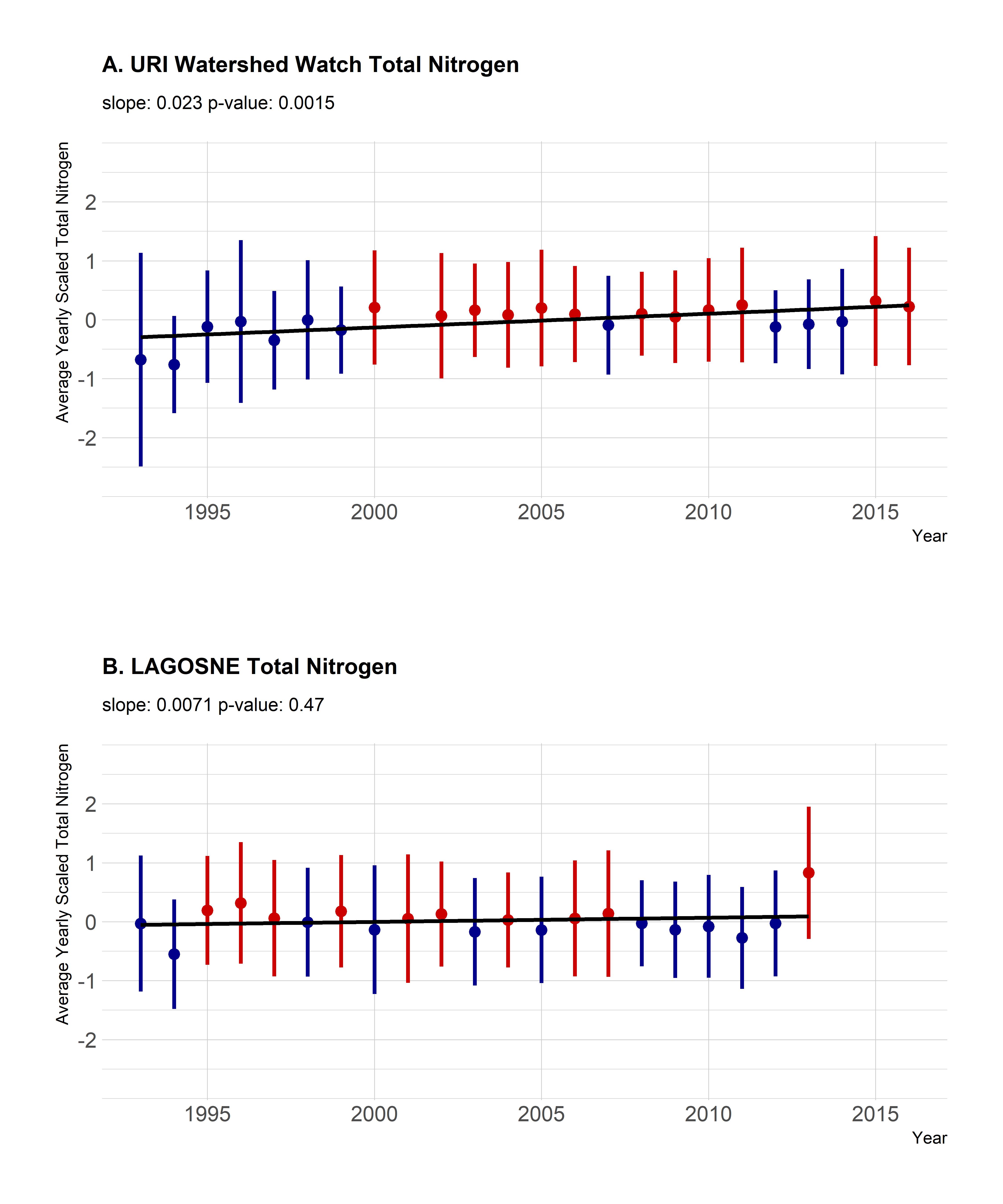


Figure 5: Yearly trend over 20+ years of total nitrogen (average z-score). Panel A. shows yearly averaged total nitrogen z-scores from the URI Watershed Watch data. Panel B. shows yearly averaged total nitrogen z-scores from the LAGOSNE dataset. Points are averages and ranges are standard deviations with blue indicating an average below the long term mean and red indicating an average above the long term mean.

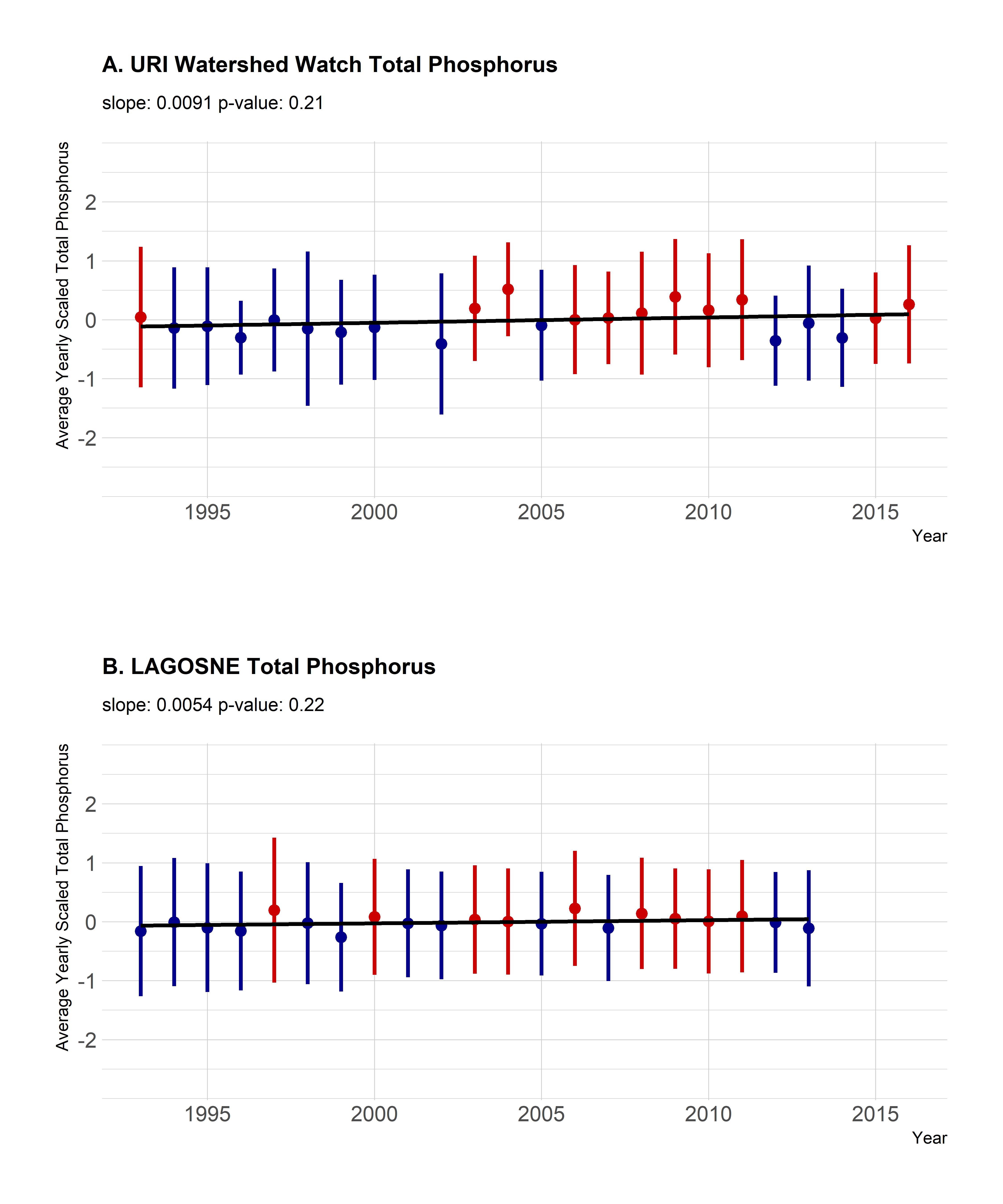


Figure 6: Yearly trend over 20+ years of total phosphorus (average z-score). Panel A. shows yearly averaged total phosphorus z-scores from the URI Watershed Watch data. Panel B. shows yearly averaged total phosphorus z-scores from the LAGOSNE dataset. Points are averages and ranges are standard deviations with blue indicating an average below the long term mean and red indicating an average above the long term mean.

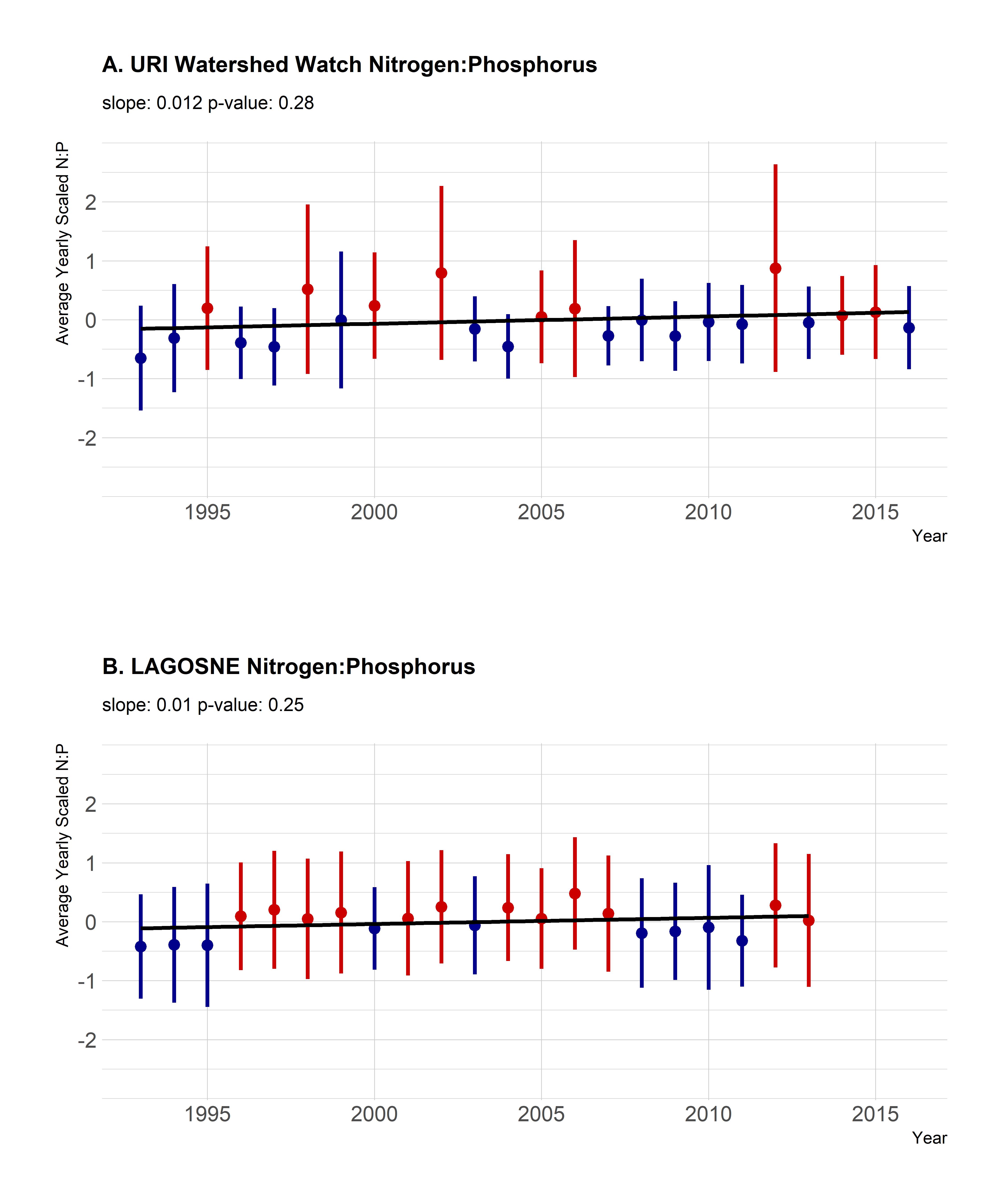


Figure 7: Yearly trend over 20+ years of the total nitrogen:total phosphorus ratio (average z-score). Panel A. shows yearly averaged total nitrogen:total phosphorus ratio z-scores from the URI Watershed Watch data. Panel B. shows yearly averaged total nitrogen:total phosphorus ratio z-scores from the LAGOSNE dataset. Points are averages and ranges are standard deviations with blue indicating an average below the long term mean and red indicating an average above the long term mean.

## Regional trends in water quality

In general, there was little to suggest broad regional trends. Chlorophyll *a* showed a very weak negative trend (slope: -0.001, p-value: 0.75122, Figure 4B.), total phosphorus shows a slight increasing trend (slope: 0.005, p-value: 0.2157, Figure 6B.), total nitrogen shows a slight negative trend (slope: 0.007, p-value: 0.46615, Figure 5B.) and the total nitrogen:total phosphorus ratio was also flat (slope: 0.01, p-value: 0.24931, Figure 7B.)

# Discussion and conclusions

Our analysis indicates that even when nutrient regimes exhibit relative stability (i.e. neither increasing nor decreasing over time), increases in productivity, as measured by chlorophyll *a*, occur. One possible explanation for this is the long-term warming of Rhode Island lakes and reservoirs as also indicated by our analysis. Second, scale does indeed matter when trying to identify long-term water quality trends as our analysis shows little increasing trend in broad scale (e.g. Northeastern and Mid-western United States) patterns of productivity, but do show clear increasing trends for just the state of Rhode Island. In the discussion that follows, we more closely address these trends, discuss broader implications of these results, and reiterate the value of the data analysis approach we used.

## Trends

As previously mentioned, both temperature and chlorophyll *a* show increasing trends from 1993 to 2016 in Rhode Island lakes and reservoirs, while total nutrients and the nitrogen:phosphorus ratio are all relatively stable. These stable nutrient regimes may be partly explained by efforts to curb nutrient loadings (e.g., [NEED REFERENCES HERE]). Additionally, these results point to the fact that productivity is driven by processes operating at different scales. For instance, controlling for nutrients is largely a local to watershed scale effort, but may also be regional as atmospheric nitrogen deposition can be a significant source of nitrogen [NEED REFERENCES HERE]. Similarly, warming lakes are driven by broader, climate patterns, yet waterbody specific factors such as percent impervious in the watershed and lake morphology can also impact temperature [NEED REFERENCES HERE]. So, when examining differences in regional and state level trends those trends are the results of complex interacting drivers.

In addition to the annualized trends we address with this study, there are other trends that may be of interest. First, what are the trends for water quality at finer temporal scales such as monthly or seasonal trends? Anecdotal evidence in Rhode Island [SHOULD REFERENCE THIS SOMEHOW] points to greater increases in temperature earlier and later in the growing season and suggests a lengthening of the growing season. Second, are trends influenced by the current state of a given waterbody? For instance, are oligotrophic lakes showing stronger trends than eutorphic lakes or are all lakes showing similar trends regardless of current trohpic status? These questions all warrant further investigation.

## Broader Implications

* Provides feedback on long term changes for managers and stakeholders
* Season Length Changes
* How to stabilize trends?
  + More reductions in nutrients?
  + Engineered solutions to slow warming?
  + Look to individual lakes that buck the trend for suggestions (e.g. local landcover may provide a buffer)
  + stable nutrients doesn’t mean they are low, just not getting worse
  + interventions to reduce nutrients could offset the suggested increase caused by temperature
    - e.g. freshwater mussels restoration

## Data Analysis Approach

* Why this is possible - Fantastic WW data
* Use of site specific z-scores
  + Other approaches available, but this one is useful because it provided readily interpretable results, robust to variations in sampling stations (i.e. added later in period, removed, etc.), and based off of approach with long history of use in exploring long term trends (Hansen et al. 2006 pp. hansen2010global, @jones1996calculating, @jones1999surface)

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