Estimating water temperatures in headwater streams within brook trout habitat
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Abstract
Brook trout (Salvelinus fontinalis) are a native and keystone species in Pennsylvania and often used as an indicator of environmental quality due to their sensitivity to water temperatures. In order to analyze the potential habitat quality for brook trout, water temperature data is required. We are using trout population data collected in a total of 65 first and second order streams, tributaries within north central and central Pennsylvania. Beginning with the two assumptions that A) first order streams are fed primarily by springs and B) annual average air temperature influences spring water temperatures because spring water has a close association with groundwater, we have designed a model to predict water temperatures within first order streams based on the site elevation as well as its local, long term weather measurements. A random group of 30 sites with water temperature measurements were used to calibrate the regression equations between elevation, site location, and water temperature. The remaining 20 sites were used as a comparison group to determine the prediction ability of the model (the remaining 30 samples had no water and no temperature measurement). We aim to eventually be able to determine the relationship between estimated water temperatures and brook trout populations. Streams containing brook trout are given a higher level of environmental protection than streams without the species in Pennsylvania and of the 61,795 streams in PA, only 8,224 of them have been sampled by the Pennsylvania Fish and Boat Commission. Over 5,000 streams remain to be sampled. Our goal is to accurately predict water temperature which will be helpful to the PFBC to allow for targeted selection of sampling sites for biological monitoring.

Introduction
Brook trout are a native species to Pennsylvania waters. As a higher order consumer, brook trout are considered a keystone species as well as an indicator species due to their resilience to changes in water quality. Because of this intolerance to water quality changes, water bodies which possess this species receive higher priority in protection of the Commonwealth of Pennsylvania. We have 61,795 streams in Pennsylvania and of those only 8,224 (13%) have been sampled to determine the wild trout populations. Brook trout thrive in waters cooler than 2°C with pH between 5.0 and 7.5. Stream temperature and pH are not recorded for first and second order streams on a statewide basis. To protect suitable trout habitat, we rely on publicly available data sets like terrain (USGS), land cover (USGS-UCS), soil properties (USDA), mining and gas exploration (PA DEP), and climate (NOAA-NCEI). The objective of this study is to develop a method to predict water temperature as a key factor of water habitat quality. This prediction tool could be used to prioritize conservation efforts in areas with the greatest likelihood of wild brook trout populations.

Methods
Geographical data sets composed for this study include:

1) Elevation data was obtained from the Shuttle Radar Topography Mission (SRTM) Elevation Dataset 2010 (www.pdsdaac.usgs.gov) to calculate stream sample site elevations.
2) Stream paths for each watershed were retrieved from the USGS National Hydrography Dataset http://nhd.usgs.gov/
3) Rainfall and air temperature averages were collected for the years 1987-2015 from the National Climatic Data Center https://www.ncdc.noaa.gov/.

Water Temperatures were collected from first and second order streams in North and Central Pennsylvania from 2000-2015 (Figure 1). During this time, two of the streams had been sampled more than once. Wild brook trout populations were collected by means of electroshocking and their length and weight were recorded.

The 30-year air temperature average was used to create a map using ArcMap 10.3.1 (ESRI, Redlands CA). We removed the effect of elevation using Microsoft Excel (Minitab, Bedford MA) and created a map of residual temperatures. Using sample site elevations, we estimated water temperature using the air temperature regression and residual temperature surface map.

Using RStudio (Rstudio, Boston MA), statistics were performed to determine a well suited equation for predicting water temperature. A linear regression was performed to calibrate air temperature to the site elevations using the formula for slope: \( y = mx + b \). It stands for the error of the line which we assume has a geographical meaning relative to latitude and other geographical factors. From here, we mapped X and Y to residual temperature.

Results

Airport weather recording stations are shown in Figure 4 along with average air temperature for 1966 to 2010. The elevation at each station was used to separate the cooling effect of mountainsous areas. We defined residual temperatures as the difference between measured air temperature and the component due to elevation. The residual temperature is shown in Figure 5 and is reasonably well-correlated to latitude.

Figure 2: A) Air temperatures are warmest in the southwest and southeast corner of the state. These areas also have the lowest elevation. The elevation effect was removed by linear regression to produce a “temperature residual.” B) After removing the elevation effect, the residual air temperature is primarily a function of latitude.

Conclusion
We developed a series of linear regressions and geostatistical methods to estimate summer water temperatures using only elevation and location of a stream site. Estimated water temperatures for many streams were quite close to measured temperatures and lie near the 1:1 line. However, many sites did not agree with estimated temperatures. More work will be conducted to try to resolve these discrepancies.

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Figure 3: Annual average air temperature decreases as the elevation of a location increases.

Figure 4: Water temperature is shown as a function of air temperature, as air temperature increases, water temperature increases.