**Introduction**

Water temperature is a key component of lotic ecosystems, determining species composition, organismal growth, and ecosystem functions and productivity (Caissie, 2006; Poff et al., 2002). Stream temperatures have risen in the last few decades (Kaushal et al., 2010) and will continue to rise as global climate change accelerates (Pörtner et al., 2022; van Vliet et al., 2013). Warming water temperature poses a major threat to the persistence of coldwater organisms, but warming rates are not spatially homogeneous due to surface-groundwater interactions and watershed and localized habitat characteristics (Lisi et al., 2013, 2015; Winfree, 2017). Identifying characteristics of stream habitats that offer refuge from climate warming and predicting their locations is critical to coldwater conservation planning (Ebersole et al., 2020).

However, a challenge lies in locating climate refugia for coldwater organisms over a broad geographic extent. Stream temperature is influenced by a multitude of atmospheric, hydraulic, and landscape characteristics and processes (Caissie, 2006; Lisi et al., 2015; Poole & Berman, 2001; Webb et al., 2008). Physical temperature models incorporate solar radiation, air-water heat transfer, evapotranspiration, and groundwater input (Caissie, 2006; Kelleher et al., 2012; Lalot et al., 2015; Sinokrot & Stefan, 1993). These processes may differ spatially due to local hydrology, riparian shading, and local landcover (Chang & Psaris, 2013; Dugdale et al., 2018; Garner et al., 2015; Mayer, 2012). These process-based modeling approaches are hard to replicate at many sites, especially for predicting temperatures at unsampled sites and consequently strategizing landscape and regional conservation efforts.

Alternatively, statistical approaches based on the relationships between stream and air temperatures have proliferated to characterize thermal variation among streams (Crisp & Howson, 1982; Erickson & Stefan, 2000; Mackey & Berrie, 1991; Mohseni et al., 1998; Mohseni et al., 1999; Morrill et al., 2005; Stefan & Preud’homme, 1993; Webb et al., 2008; Zhu et al., 2018). Stream-air temperature relationships have been represented by linear (REF) or nonlinear (i.e., logistic) regression (Mohseni et al., 1998; Mohseni & Stefan, 1999). The nonlinear approach is suited in regions characterized with low (<0 °C) and high (>25 °C) air temperatures. Specifically, stream temperature typically stays above 0 °C when surface ice forms in winter, and at elevated air temperature in summer, evaporative cooling mitigates warming rates (Mohseni et al., 1998; Mohseni & Stefan, 1999). Stream-air temperature relationships have been modeled hourly, daily, and weekly (Caissie et al., 2001; Stefan & Preud’homme, 1993; Webb & Nobilis, 1997), with a time lag between stream and air temperature diminishing over longer temporal scales and thus the tightest stream-air temperature relationships at weekly scales (Kelleher et al., 2012). Sensitivity of stream temperature relative to changes in air temperature is typically used as an indicator of groundwater input, where more temporally stable stream temperature amid air temperature fluctuations signifies climate refugia (Beaufort et al., 2020; Hare et al., 2023; Kelleher et al., 2012).

DespiteI our increasing knowledge of spatial variability in thermal sensitivity, uncertainty persists as to whether this spatial variability can be sufficiently explained and predicted by readily available watershed and hydrological data at the national and regional scale (e.g., National Hydrography Dataset (NHD) in the USA). These broad-scale data sets inherently provide coarse-scale habitat characterization; for example, the NHD contains habitat data at the stream segment scale, defined as the length of streams between two confluences or from the headwater to the first confluence downstream. Thus, spatial heterogeneity within stream segments and highly localized processes (i.e., groundwater seepage) could be missed, limiting our ability to locate climate refugia. Despite potential limitations, spatial variability in thermal sensitivity has been attributed to coarse-scale habitat metrics such as riparian conditions, stream size, and geology (Beaufort et al., 2020; Chang & Psaris, 2013; Mayer, 2012; Tague et al., 2007; Toffolon & Piccolroaz, 2015). As broad-scale stream habitat data become increasingly available, it is important to test their ability to explain and predict thermal sensitivity over a broad geographic extent to inform management of coldwater species of conservation concern.

Brook trout (*Salvelinus fontinalis*) is a coldwater salmonid whose native distribution covers much of eastern North America. Brook trout populations have declined greatly, particularly at its southern native range, due to anthropogenic factors such as habitat loss and fragmentation, non-native species, and introgression with hatchery fish (Hudy et al., 2008; Kazyak et al., 2022). As a coldwater species, they cannot withstand prolonged periods of water temperatures higher than 22-24 °C (Eaton et al., 1995; Hartman & Cox, 2008; Wehrly et al., 2007). Riverscapes in which brook trout can access areas with cool stream temperatures allow them to persist through heat waves and droughts (Hitt et al., 2017; Petty et al., 2012; Trego et al., 2019). Thus, the ability to identify and predict thermally suitable brook trout habitat over a long period (i.e., climate refugia) is of great importance for prioritizing streams for conservation and restoration action such as habitat improvement, physical barrier removal, non-native trout removal, and brook trout translocations (Kanno et al., 2016; White et al., 2022). Stream temperatures have been modeled for brook trout streams in their native range, including the use of paired stream-air temperature measurements (Kanno et al., 2014; Letcher et al., 2016; Trumbo et al., 2014). However, these studies were limited in their geographical extent and we are not aware of previous work which combined paired stream-air temperature measurements with readily available watershed and hydrological data to describe and predict thermal sensitivity of streams at the regional scale.

Here, we characterized landscape influences on stream thermal sensitivity across the native range of brook trout in the southern and central Appalachian Mountains regions, USA (~ 1,000 km), using a multi-year data set of paired stream and air temperature measurements. Located at their southernmost native range, brook trout have suffered the greatest declines in the study area (Hudy et al., 2008). Our study objectives were two-fold. First, we used widely available landscape and hydrologic metrics to identify determinants of stream thermal sensitivity with a Bayesian hierarchical model of nonlinear relationships between weekly average stream and air temperatures. Second, we used this model to predict thermal sensitivity at unsampled brook trout habitats throughout the study area. In addressing these objectives, we aimed to quantify how much thermal sensitivity varied among streams in the study area and its correlation with landscape characteristic and identify locations of climate refugia for brook trout in a warming world.