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Comment on Meisner (1990): Effect of Climatic Warming on the Southern Margins of the Native Range of Brook Trout, *Salvelinus fontinalis*

Meisner (1990) proposed in the *Journal* that the lower elevational margin of brook trout (*Salvelinus fontinalis*), in the southern part of their native range is related to the 15°C groundwater isotherm, based on a modelled relationship between minimum elevations at which brook trout occur in this part of the native range and elevation, latitude, and groundwater temperature. Furthermore, he estimated minimum elevations for brook trout under the warming scenario of the Goddard Institute for Space Studies (GISS) that projects a 3.8°C increase in mean annual temperature. He presented a crude map of the areas remaining available to brook trout as "potential habitat" under the GISS scenario, but was unable to provide details. He had selected from state inventories the site lowest in each drainage that had brook trout and consequently did not have the entire inventory data set available for the projection. According to Meisner (1990, fig. 3) the distribution of brook trout in North Carolina and Virginia under the GISS scenario would become relatively patchy, and trout would disappear altogether from Tennessee, South Carolina, and Georgia. I was able to apply Meisner's (1990) model to the complete data sets from the North Carolina Wildlife Resources Commission (Bonner 1983) and Virginia Department of Game and Inland Fisheries (Mohn and Bugas 1980) and offer here results and some additional comments.

I extracted from Meisner's (1990) fig. 2 the lower stream boundary under the GISS warming scenario:

$$\mathrm{ELEV} = 7528 - 178.6 \cdot \mathrm{LAT}$$

where latitude is in degrees north and elevation is in metres. The state agencies had assigned elevation to all 1311 streams in the complete inventories and I assigned latitude based on locations on 7.5-min USGS quadrangle sheets. For Virginia streams, I used midpoints of the quadrangle sheets rather than actual latitudes, but the error of using midpoints in the equation above is only 11 m, within the range of error associated with estimating elevations in the inventory database.

Out of 528 streams that had brook trout at the time the inventories were conducted (1978–81 in North Carolina and 1975–79 in Virginia), only 58 would have brook trout under the warming scenario, a loss of 89% of the brook trout streams. A greater loss would occur in Virginia than in North Carolina: in Virginia, only 32 out of 380 brook trout streams would remain, a loss of 92%; and in North Carolina, 26 out of 148 brook trout streams would remain, a loss of 82%. More high-elevation stream habitat is available in North Carolina to harbor brook trout under a warmed climate than is available in Virginia. These results may be optimistic because 32 streams above the minimum elevation specified by the equation above already lack brook trout. In these streams, local stream habitat conditions may be unsuitable or brook trout have already been eliminated

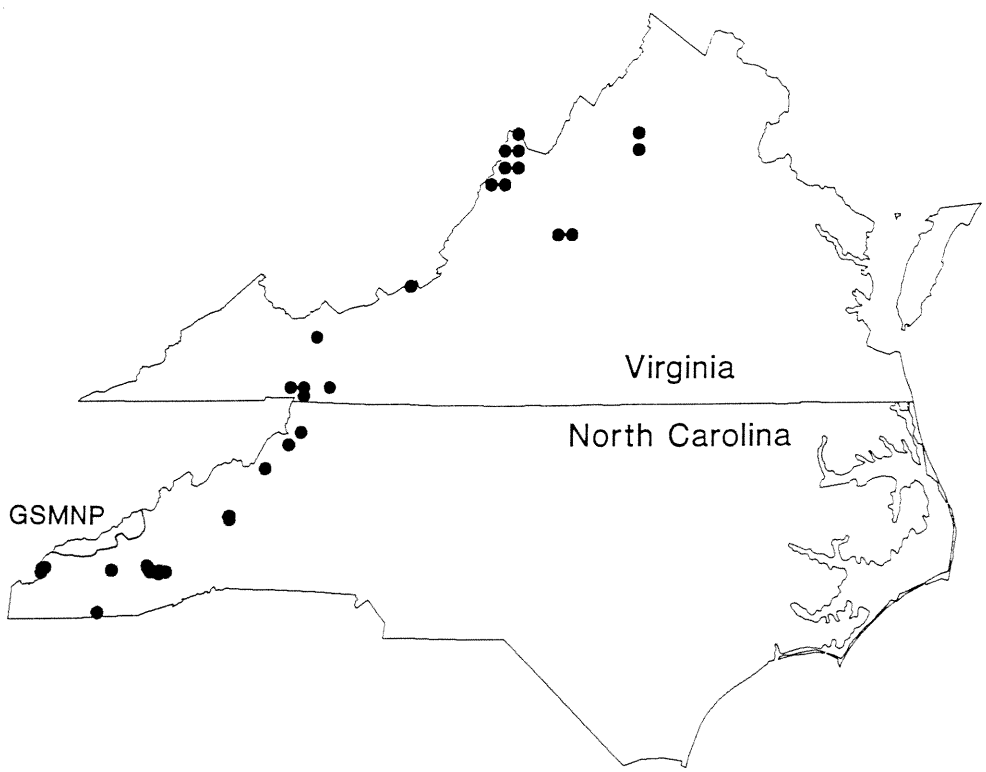

FIG. 1. Location of 58 brook trout streams surveyed in Virginia (1975–79) and North Carolina (1978–81) that would remain above the 15.4°C isotherm under the GISS climate warming scenario, based on the model of Meisner (1990). Each dot may represent more than one stream. The boundary of Great Smoky Mountains National Park (GSMNP) in North Carolina is indicated.

by encroachment by rainbow (*Oncorhynchus mykiss*) and brown trout (*Salmo trutta*). Under global warming, some of these processes may further erode the habitat available for brook trout.

The distribution of these remaining brook trout streams (Fig. 1), although not inconsistent with Meisner's (1990) map, is considerably more fragmented than his map suggests. Part of the fragmentation is because the original inventory represents a sample of all streams, but the sample was sufficiently complete to cover adequately the cold-water stream area of the states. The single exception is that the Great Smoky Mountains National Park along the North Carolina – Tennessee border (see Fig. 1) was not sampled. This high-elevation area should continue to harbor brook trout in some streams under the GISS warming scenario. Other causes of the observed fragmentation are of real concern under a warming scenario. Like all mountainous areas, if only the upper elevations remain available to brook trout, their habitat will take the form of islands on the tops of mountains. At the uppermost elevations, only very small first-order streams remain, and these may be inadequate to support brook trout, particularly under low-flow conditions. In small headwater streams of the Great Smoky Mountains National Park, trout populations occasionally disappear and can only be recolonized from downstream reaches (C.A. Dolloff, USDA Forest Service, Fisheries and Wildlife Department, Virginia Tech, Blacksburg, VA, personal communication), but if these downstream populations are eliminated under warming, these sources of recolonization are not available — Patricia A. Flebbe, *USDA Forest Service, Southeastern Forest Experiment Station and Department of Fisheries and Wildlife Sciences, Virginia Polytechnic Institute and State University, Blacksburg, VA 24061-0321, USA* (JB617)

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Reply to Flebbe (1993)

Flebbe (1993) has provided a map showing approximate locations of brook trout streams in the native range in Virginia and North Carolina that would remain in the Goddard Institute for Space Studies' (GISS) climate warming scenario (Smith and Tirpak 1989). The streams are located at, or above, the altitude of the lower margin of the native range that I projected would exist in the GISS scenario (Meisner 1990). The lower margin of the southern part of the native range in the GISS scenario, as accurately described by Flebbe's regression of altitude on latitude, reflects the altitude of the 15°C groundwater isotherm, which shapes the lower altitude of brook trout (*Salvelinus fontinalis*) streams in the southern part of the native range (Meisner 1990) such as in Virginia and North Carolina. Flebbe and I used the same stream inventories for Virginia and North Carolina to map the brook trout distributions.

Flebbe's map clarifies the potential effects of climate change on the brook trout distribution in Virginia and North Carolina, based on my groundwater model and the application of the model in the GISS scenario. The distribution of brook trout streams in North Carolina and Virginia in Flebbe's map is more fragmented than the distribution in these states shown in my map (Meisner 1990, Fig. 3) because my map represents an estimate of area of land above the lower distributional boundary, not the locations of brook trout streams. Due to data constraints, as partially restated by Flebbe, I chose to estimate area of the native distribution that would be available to brook trout in a warmer climate. At the time of my study, complete inventories of stream fishes in the native brook trout range were available for some states, but essentially nonexistent for others (e.g., Georgia, South Carolina, and West Virginia).

As a point of correction, I did not state in Meisner (1990) that brook trout habitat would completely disappear in Tennessee in the GISS scenario. On the contrary, as stated in the Results section, Tennessee would probably lose relatively little brook trout habitat. The projected losses for Tennessee are low because most brook trout streams in that state are at altitudes above the projected lower stream boundary in the GISS scenario. A comprehensive inventory of brook trout habitat in Tennessee, including the Great Smoky Mountains National Park, is provided in Bivens (1984).

Flebbe's use of stream inventories for Virginia and North Carolina to identify potential residual brook trout streams in the GISS climate warming scenario points to the existence of other high-altitude, but brook-trout-devoid, streams in the southern part of the native range that may become important refugia for brook trout in a warmer climate. Flebbe reports that 32 of these streams exist for Virginia and North Carolina. Future brook trout rehabilitation/enhancement programs in these states may need to focus efforts on these streams in the advent of global warming. Flebbe's point of the potential development of mountain-top islands of brook trout habitat with climate change is on the mark. The projected brook trout distribution in the GISS scenario in my fig. 3 (Meisner 1990) is a first approximation of these islands. This and Flebbe's map underscore the need to assess the quantity and quality of brook trout and non-brook-trout streams that currently exist in the southern part of the native range at altitudes that would probably be unaffected by climate change. It would be helpful if investigators from the other states of the southern native range followed Flebbe's lead and pooled their stream data to complete the map of brook trout streams remaining in the GISS warming scenario — J. Donald Meisner, *ESSA Environmental and Social Systems Analysts Ltd., 9555 Young Street, No. 308, Richmond Hill, Ont., Canada L4C 9M5.* (JB650)

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