



# The NorWeST Regional Stream Temperature Model For High-Resolution Climate Vulnerability Assessments

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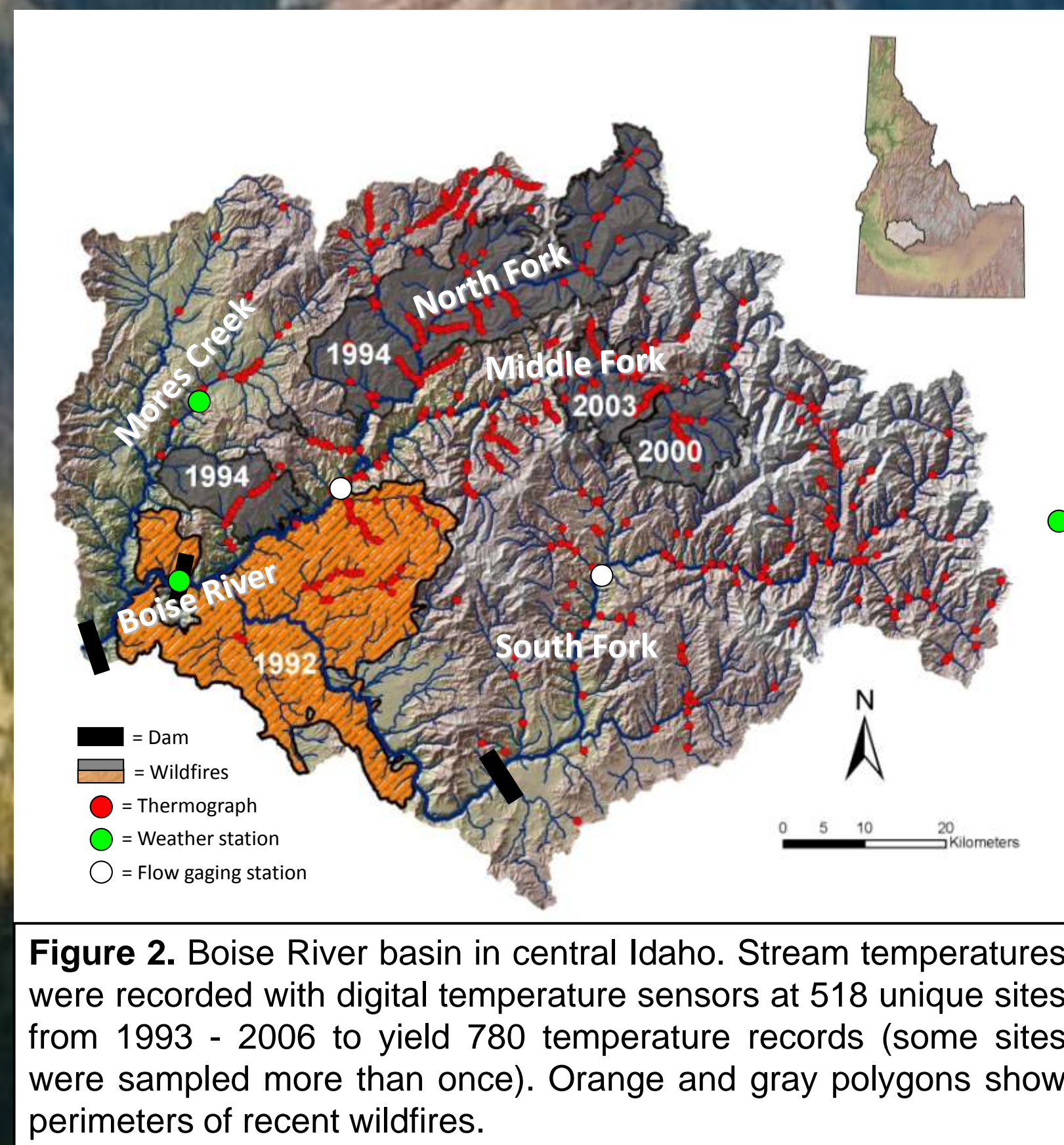


## Introduction

Climate change this century will profoundly affect streams across the Northwest U.S. where valuable cold-water fisheries exist and distributions of many trout and salmon species are already constrained by warm temperatures (Rieman and Isaak 2010; Isaak et al. 2012). Several regional assessments of temperature increases on fish distributions have been done (e.g., Rieman et al. 2007; Williams et al. 2009; Haak et al. 2010; Wenger et al., 2011) but all rely on air temperature as a surrogate for stream temperature. These temperatures are often weakly correlated in streams and rivers of the Northwest that drain complex mountain topographies (Figure 1). Methods are needed for accurately and consistently modeling stream temperatures across broad areas to improve the accuracy of vulnerability assessments and improve conservation planning.

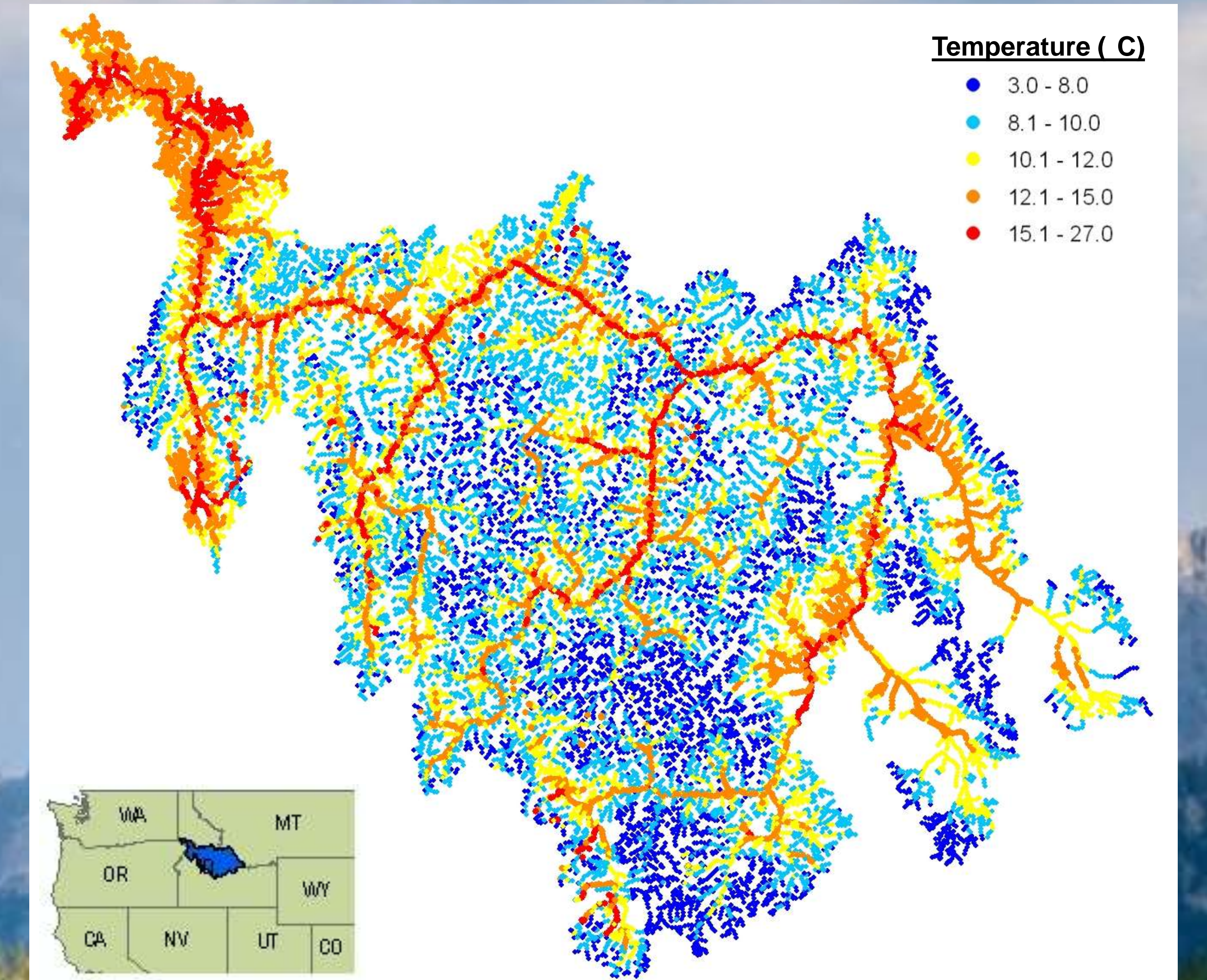
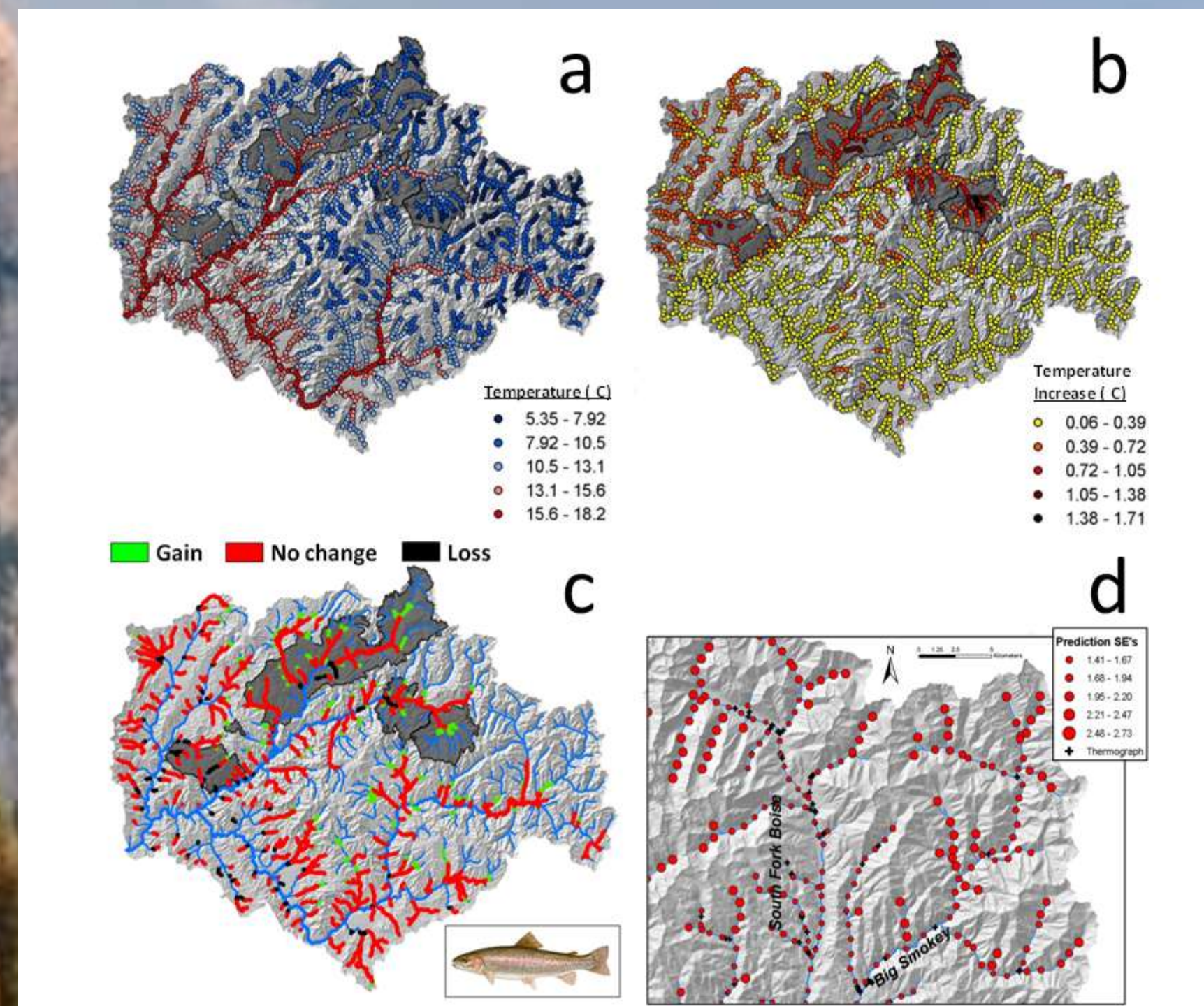
## Example Application

In a pilot study, the spatial statistical stream models were applied to a large database (n = 780) of summer stream temperature measurements compiled for the 2,500 km Boise River network in central Idaho (Figure 2; Isaak et al. 2010). The temperature measurements were obtained from numerous resource agencies (IDFG, BOR, USFS, RMRS, DEQ, Boise City) and encompassed a 13 year period from 1993 – 2006.



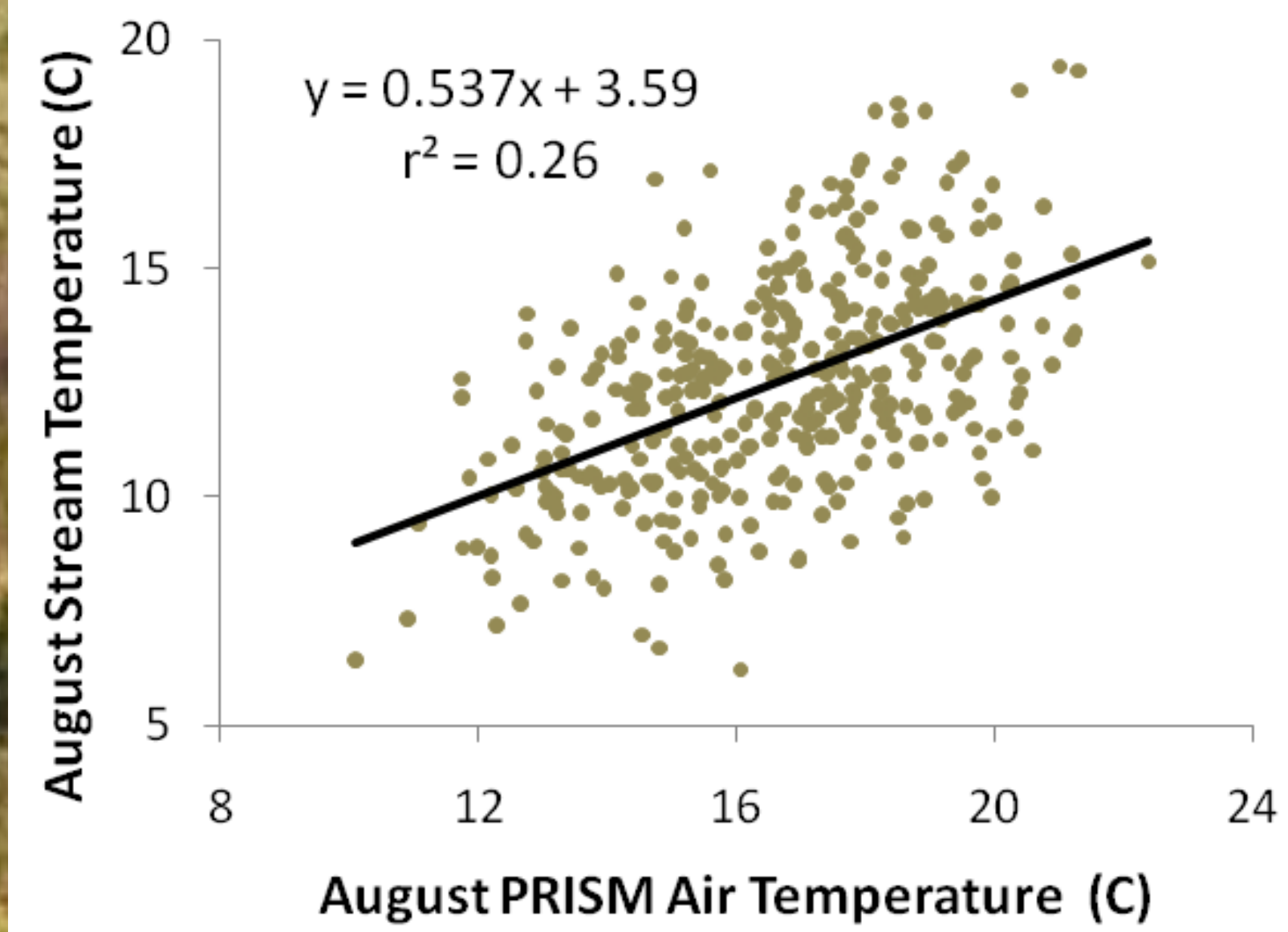
**Figure 2.** Boise River basin in central Idaho. Stream temperatures were recorded with digital temperature sensors at 518 unique sites from 1993 - 2006 to yield 780 temperature records (some sites were sampled more than once). Orange and gray polygons show perimeters of recent wildfires.

Once the spatial model has been fit to a stream temperature database, a variety of useful outputs can be generated. These include: a) maps of stream temperature for addressing water quality concerns, b) description of historic and future climate change scenarios, c) thermal habitat maps for aquatic species, and d) spatially-explicit descriptions of model precision for design of efficient monitoring protocols (Figure 4).



**Figure 6.** Map of August stream temperatures for the 2002-2011 period predicted at 1 kilometer resolution from a temperature model fit to NorWeST data in the Salmon River basin of central Idaho. The model accounted for 90% of the variation in observed temperatures and includes parameters for climate covariates such as air temperature and stream discharge that can be used to may different historic and future climate scenarios.

## Air Temp ≠ Stream Temp



**Figure 1.** Scatterplot showing the relationship between air temperature and stream temperature. The bias and imprecision resulting from the use of air temperature instead of stream temperature incorporates significant uncertainty to bioclimatic models of trout and salmon distributions and limits the effectiveness of conservation planning at broad scales.

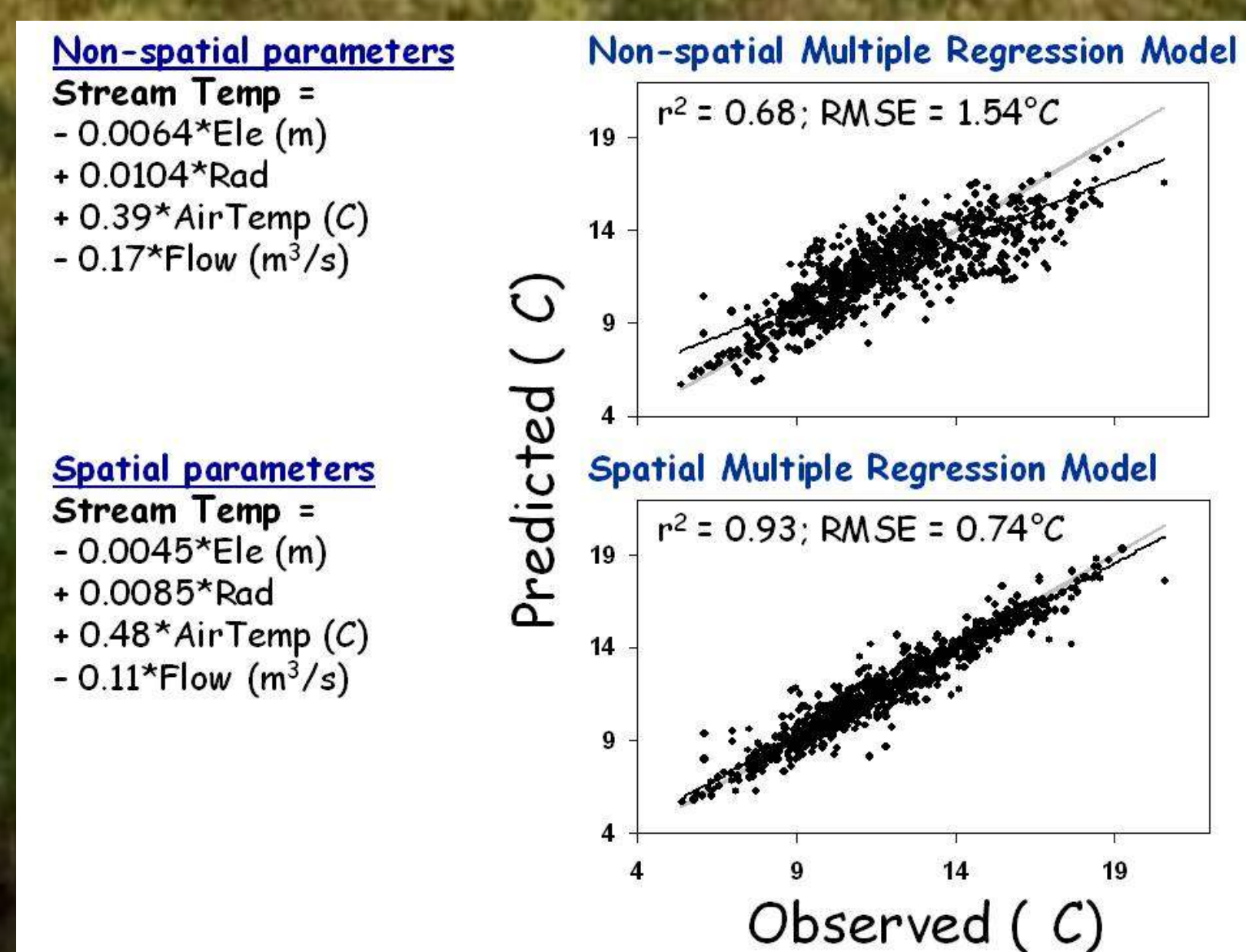
The advent of inexpensive and reliable digital sensors in the 1990s made collection of stream temperature data convenient and many resource agencies routinely collect this information. Significant amounts of summer temperature measurements exist that could be used to build a regional temperature model. One challenge in working with large databases compiled from multiple sources is that sample locations are often non-randomly distributed and strongly clustered in space. These issues may bias parameter estimates in temperature models and subsequent predictions unless appropriate analyses are applied.



## Spatial Stream Models

A new class of spatial statistical model has recently been developed that accounts for the structure of stream networks (e.g., longitudinal connectivity, flow-volume, and flow-direction) and the unique forms of spatial dependence among observations on networks (Ver Hoef et al. 2006; Peterson et al. 2007). These models can be used to derive unbiased parameter estimates from non-random databases and often have improved predictive accuracy compared to traditional models.

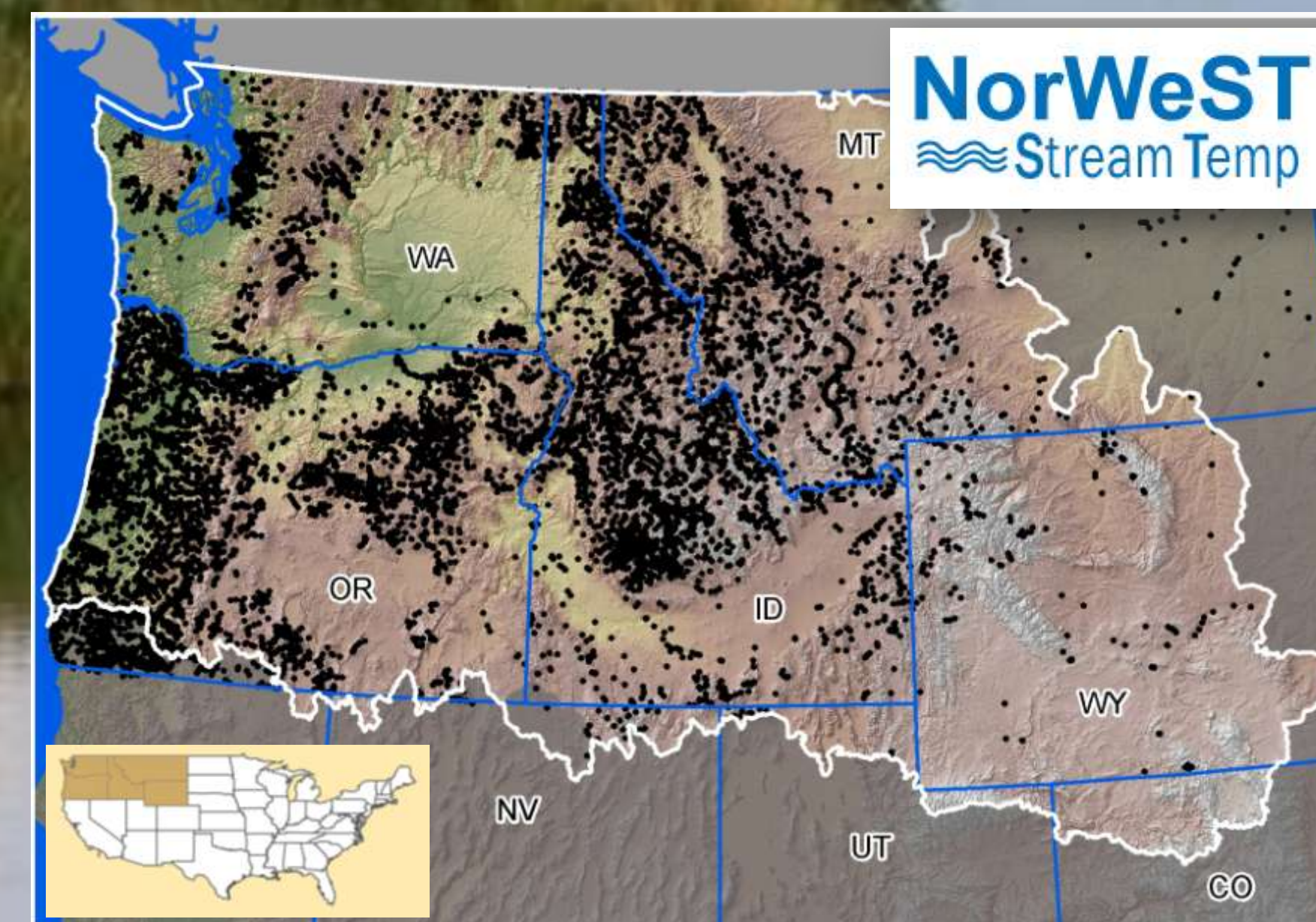
Stream temperature predictions from the spatial models fit to these data were precise and unbiased (Figure 3, bottom panel). Moreover, these results were much more accurate than a traditional, non-spatial regression model (Figure 3, top panel). Parameter estimates differed between the temperature models, indicating that autocorrelation among temperature observations biased the results of the non-spatial model.



**Figure 3.** Scatterplots of predicted mean summer stream temperatures versus observed values for a non-spatial multiple regression model (top panel) and the spatial regression model (bottom panel). Grey line indicates 1:1 relationship; black line is simple linear regression between predicted and observed.

## GNLCC Temperature Project

A project funded by the Great Northern LCC was initiated in 2011 to apply the spatial stream models broadly in development of a regional temperature model (Isaak et al. 2011). The first stage of this project consisted of developing the comprehensive, interagency stream temperature NorWeST database (Figure 5). This database contains >45,000 summers of temperature measurements recorded at >15,000 unique stream sites and may be the largest database of its kind in the world. The second stage of the project consists of modeling NorWeST data to develop a consistent set of historic and future stream temperature scenarios for all of the 350,000 stream kilometers in the Northwest U.S. The first such model was recently developed for the Salmon River basin in central Idaho (Figure 6).



**Figure 5.** Map showing locations of stream temperature data in the NorWeST database across the project domain that encompasses most of Idaho, Montana, Wyoming, Washington, and Oregon. Copies of >45,000 summers of temperature measurements recorded at >15,000 unique stream sites have been compiled in this database.

## Discussion

Temperature data within subdomains like the Salmon River basin will be modeled across the region over the next year to develop consistent sets of climate scenarios for all streams in the Northwest U.S. A NorWeST webpage will be launched in the winter of 2012 to disseminate the geospatial data layers representing these scenarios and temperature data summaries. These data will provide numerous benefits to resource agencies throughout the region and have value that extends well beyond the funding for this project. The temperature data assembled in the NorWeST database alone would require an investment of more than \$10,000,000 to collect. A much greater value, however, will accrue over time from more efficient management and monitoring efforts that are informed by the spatial data developed in this project. A series of complimentary projects using these data are being developed that include: 1) regional temperature and biological monitoring networks, 2) vulnerability assessments for sensitive species, 3) decision support tools, 4) consistent descriptions of thermal niches, and 5) improved bioclimatic models for aquatic organisms.

As this project progresses, it is developing considerable interest and support across the region, stimulating collaborations and coordination among resource agencies, and serving as a model for initiatives in other parts of the country through the Landscape Conservation Cooperative system. We gratefully acknowledge the support of the U.S. Fish & Wildlife Service in this endeavor and the hundreds of biologists and hydrologists from dozens of resource agencies that submitted data to NorWeST.

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