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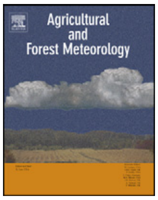

Three centuries of shifting hydroclimatic regimes across the Mongolian Breadbasket

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ABSTRACT

In its continuing move toward resource independence, Mongolia has recently entered a new agricultural era. Large crop fields and center-pivot irrigation have been established in the last 10 years across Mongolia's "Breadbasket": the Bulgan, Selenge and Tov aimags of northcentral Mongolia. Since meteorological records are typically short and spatially diffuse, little is known about the frequency and scale of past droughts in this region. We use six chronologies from the eastern portion of the breadbasket region to reconstruct streamflow of the Yeruu River. These chronologies accounted for 60.8% of May–September streamflow from 1959 to 1987 and 74.1% from 1988 to 2001. All split, calibration-verification statistics were positive, indicating significant model reconstruction. Reconstructed Yeruu River streamflow indicates the 20th century to be wetter than the two prior centuries. When comparing the new reconstruction to an earlier reconstruction of Selenge River streamflow, representing the western portion of the breadbasket region, both records document more pluvial events of greater intensity during 20th century versus prior centuries and indicate that the recent decade of drought that lead to greater aridity across the landscape is not unusual in the context of the last 300 years. Most interestingly, variability analyses indicate that the larger river basin in the western breadbasket (the Selenge basin) experiences greater swings in hydroclimate at multi-decadal to centennial time scales while the smaller basin in the eastern portion of the breadbasket (the Yeruu basin) is more stable. From this comparison, there would be less risk in agricultural productivity in the eastern breadbasket region, although the western breadbasket region can potentially be enormously productive for decades at a time before becoming quite dry for an equally long period of time. These results indicate that farmers and water managers need to prepare for both pluvial conditions like those in the late-1700s, and drier conditions like those during the early and mid-1800s. Recent studies have indicated that cultures with plentiful resources are more vulnerable when these resources become diminished. Thus, the instrumental records of the 20th century should not be used as a model of moisture availability. Most importantly, the geographic mismatch between precipitation, infrastructure, and water demand could turn out to be particularly acute for countries like Mongolia, especially as these patterns can switch in space through time.

1. Introduction

Climate change will have a significant impact on agricultural and ecological systems. In fact, warming has already had a significant impact on productivity and prices for important crops like maize and wheat over recent decades (Piao et al., 2010; Dronin and Kirilenko, 2010; Lobell et al., 2011; Urban et al., 2012; Diffenbaugh et al., 2012). It is not entirely clear how these systems will respond to future climate change, or how these responses will vary spatially. Although it was initially thought that climate change would benefit agricultural production in high latitude regions (Dronin and Kirilenko, 2010), productivity has not necessarily improved due to climatic change over the last 60 years. One striking example is the 2010 heat wave in Russia where the unusual heat exacerbated drought and triggered a significant drop in grain production in some regions (Grumm, 2011; Wegren, 2011). Similarly, higher

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temperatures exacerbated drought conditions, which triggered tree mortality and an ecotonal shift in a forested ecosystem in the southwestern U.S. (Breshears et al., 2005), a pattern seen in other forested ecosystems globally (Allen et al., 2010). Understanding the interaction between climate change and agricultural and ecological systems is vital to ensure resource security.

In its continuing move toward resource independence, Mongolia recently began a new and concerted effort to develop its agricultural resources, Tselina_3 (Regdel et al., 2012). Traditionally, nomadic pastoralism, coupled with agriculture during times of above average rainfall, has been a common land-use strategy in Mongolia (Lattimore, 1938; Humphrey and Sneath, 1999; Fernández-Giménez, 2000), as is typical in other regions that experience tremendous spatial and temporal variability in water resources (Batisani and Yarnal, 2010; Mary and Majule, 2009; Fiebig-Wittmaack et al., 2011). Recent factors have triggered increased concern over food security in Mongolia including: (1) increasing human population (National Statistics Office of Mongolia, 2012), (2) increases in water-demanding activities, including mining (Priess et al., 2011), (3) growing herd populations and alteration of nomadic migration patterns that have led to intensive usage and subsequent degradation of pastures (e.g. Enkh-Amgalan et al., 2012; Regdel et al., 2012), and (4) general vulnerability to climate change (Gregory et al., 2005; Batima et al., 2005). This increase in concern over food security has been especially true for nations in central Asia, like Mongolia, that were directly impacted by the fall of the Soviet Union (Lioubimtseva and Henebry, 2009). According to a study by Rockstrom et al. (2007), 20–35% of the Mongolian population was undernourished from 2001 to 2002 following a severe drought, a condition that is not uncommon in semi-arid regions with highly variable rainfall. As a result of these concerns, government spending in the food and agricultural sectors of Mongolia increased significantly between 2005 and 2009 (FAO, 2011). The Tselina_3 program, otherwise known as the Third Campaign of Reclaiming Virgin Lands, was an attempt to further stimulate domestic agriculture for increased self-sufficiency and the prevention of future food crises (Bayar, 2008). Of the 156.4 million hectares of Mongolian territory, currently 617.1 thousand hectares are sown for agriculture (Regdel et al., 2012), and large crop fields and center-pivot irrigation are being established across Mongolia's "Breadbasket": the Bulgan, Selenge, and Tov aimags of northcentral Mongolia (Fig. 1a and b).

Instrumental records indicate that Mongolia has generally warmed 1.6 °C since the mid-20th century and has experienced several severe droughts since the late-1990s (Batima et al., 2005). Climatic trends like these can significantly impact developing, semi-arid nations (Lioubimtseva and Henebry, 2009). In Mongolia, these trends, in combination with severe winters (dzud), have been detrimental to important pastoral productivity (Siurua and Swift, 2002; Angerer et al., 2008). In particular, the droughts seem to be longer and more intense than ever in the collective memories of pastoralists (Marin, 2010). Placing spatial and temporal variability of recent climate change in Mongolia in a historical context is difficult because instrumental data are limited in number, space, and length. The historical extent and severity of droughts in the Mongolian Breadbasket, therefore, cannot be ascertained with instrumental records alone.

Tree-ring data have been used to reconstruct hydroclimatic or drought variability in eastern Mongolia (Pederson et al., 2001; Davi et al., under revision), the Selenge River region in central Mongolia (Davi et al., 2006), far western Mongolia (Davi et al., 2009), and across Mongolia as a whole (Davi et al., 2010). However, none of these studies have fully captured climatic variability specifically in northern Mongolia because until recently, only one drought-sensitive tree ring record existed within much of the Mongolian Breadbasket region (see map, Fig. 1 in Davi et al., 2010). Further, no annually resolved long-term paleohydroclimatic studies have been conducted in southern Siberia, immediately north of our study region (though see Voropay et al., 2011 for a contemporary review and Orkhonselenge et al., 2012 for a recent sediment core investigation). Due to high spatial variability in hydroclimate across Mongolia, as evidenced by instrumental records (Batima et al., 2005) and the aforementioned tree-ring based reconstructions, it is important to sufficiently describe this variability from a historical perspective. Quantifying long-term drought variation in the Mongolian Breadbasket will further our understanding of how historical and recent hydroclimatic patterns might differ relative to previously studied regions in Mongolia.

We collected five chronologies in northern Mongolia from sites that appeared to contain drought-sensitive trees since 2009 (Fig. 1c and d). A spatiotemporal analysis of 20 hydrometeorological records across central and eastern Mongolia, including these new records, indicates that the breadbasket region is climatically distinct from neighboring regions (Leland, 2011; Leland et al., in review). Here we build from this work to create the first hydroclimatic reconstruction in northern Mongolia. Not only is this region important agriculturally, it represents the transition from the southern boreal forest as it grades into taiga of northern Mongolia and southern Russia. Recent changes in hydroclimate might have important impacts on the ecology of the ecosystems in this region (e.g. Dulamsuren et al., 2010, 2011).

2. Methods

2.1. Tree-ring data

We collected tree-ring samples from five sites in northern Mongolia, a region that was a gap in the pre-existing, Mongolian-American Tree Ring Project network (Fig. 2, Table 1). Of the six tree-ring sites used in this study, only data from Undur Ulaan were collected in 2002 and used in previous studies (Davi et al., 2006, 2010). Tree-ring data from the other five sites were collected in summer 2009 and 2010. Some sites exhibited obvious dry conditions, with steep slopes, well-drained soils, and open-canopied trees (e.g. DKN and SMN; Fig. 1c and d) while others were heavily vegetated with closed-canopy conditions (e.g. BG, SJD). We targeted trees with classic old-growth morphology for coniferous trees (i.e. loss of apical dominance, spike tops, smooth bark pattern, and low stem taper; Swetnam and Brown, 1992; Huckaby et al., 2003) and extracted two cores per tree, when possible, with a 5.15 mm diameter increment borer. All cores were processed using standard techniques (Stokes and Smiley, 1968), beginning with fine sanding and visual crossdating of cores. We measured the annual growth rings on each core to a precision of 0.001 mm, and all dating underwent quality control with the program COFECHA (Holmes, 1983).

In order to produce a chronology for each site, individual tree-ring series were standardized using the program ARSTAN (Cook, 1985; Cook and Krusic, 2011). A data-adaptive power transformation was applied to each series in order to stabilize variance through time (Cook et al., 1992; Cook and Peters, 1997). Where necessary, a double detrending procedure was used to account for: (1) allometric growth trends and (2) abrupt pulses in growth likely associated with stand dynamics. The latter were more prevalent in sites with closed-canopy conditions and tree-to-tree competition (Cook, 1985; Cook and Peters, 1981). To remove the effect of allometric growth trends, we applied a linear or negative exponential curve to each series. In the few cases where time-series of radial growth provided visual evidence of changes in tree-level competition (Lorimer and Frelich, 1989) or abrupt reductions in growth like ice storm damage (Lafon and Speer, 2002), a second detrending was conducted with the Friedman Super Smoother