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Linking livestock snow disaster mortality and environmental stressors in the Qinghai-Tibetan Plateau: Quantification based on generalized additive models

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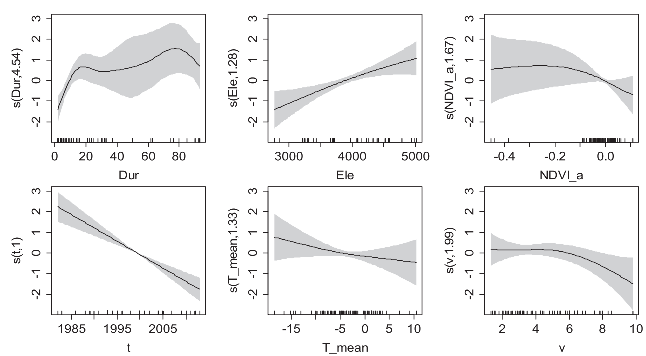
HIGHLIGHTS

- The relationship between livestock snow disaster loss and environmental stressors is quantified with GAMs.
- Snow duration was the dominant factor in snow hazard intensity, rather than snow depth/cover.
- Wind and temperature imposed significant during disaster environment stress on livestock.
- Summer vegetation had significant lagged impact on livestock snow disaster losses in the winter.
- Anomalies of NDVI or precipitation were superior to their raw values to catch the lagged effects of summer vegetation.

GRAPHICAL ABSTRACT



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ABSTRACT

Livestock snow disaster occurs widely in Central-to-Eastern Asian temperate and alpine grasslands. The effects of snow disaster on livestock involve a complex interaction between precipitation, vegetation, livestock, and herder communities. Quantifying the relationship among livestock mortality, snow hazard intensity, and seasonal environmental stressors is of great importance for snow disaster early warning, risk assessments, and adaptation strategies. Using a wide-spatial extent, long-time series, and event-based livestock snow disaster dataset, this study quantified those relationships and established a quantitative model of livestock mortality for prediction purpose for the Qinghai-Tibet Plateau region. Estimations using generalized additive models (GAMs) were shown to accurately predict livestock mortality and mortality rate due to snow disaster, with adjusted-R^2 up to 0.794 and 0.666, respectively. These results showed that a longer snow disaster duration, lower temperatures during the disaster, and a drier summer with less vegetation all contribute significantly and non-linearly to higher mortality (rate), after controlling for elevation and socioeconomic conditions. These results can be readily applied to risk assessment and risk-based adaptation actions.

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1. Introduction

Livestock snow disaster is a serious winter weather issue in pastoral areas in which deep snow, severe cold, and other conditions render forage unavailable or inaccessible, thus leading to high livestock mortality (Fernández-Giménez et al., 2012). Livestock snow disaster occurs widely in central and eastern Asia, including the Mongolian Plateau, the Qinghai-Tibetan Plateau, and from northern Xinjiang to central Asia (Tachiiri et al., 2008). These areas represent semi-arid regions supporting nomadic grazing, yet experiencing heavy snowfalls in harsh winters. Livestock snow disaster is also known as the *dzud* in Mongolian (Sternberg and Batbuyan, 2013), *dzhut* in Kazakhstan (Robinson and Milner-Gulland, 2003), and *baizai* (white disaster) in China (Ye et al., 2017). Together with other ecological and economic stressors, livestock snow disasters have led to devastating impacts on the livelihoods of local herdsmen, even threatening their survival (J. Wang et al., 2013; Y. Wang et al., 2013). Severe losses have been experienced historically, i.e. the 2009–2010 Mongolia *dzud* (30% mortality rate; Fernández-Giménez et al., 2012), the 1977 *white disaster* in Eastern Inner Mongolia (up to 70% mortality rate; Wen, 2008a), and the 1967 snow disaster in the Tibetan region (35% mortality rate; Wen, 2008b). Recently, research has indicated that the changing climate is likely to bring considerable uncertainty in the future status of vegetation and winter precipitation in these regions (IPCC, 2012). Consequently, there have been increasing concerns regarding future challenges of disaster risk reduction and climate change adaptation in those regions (Fernández-Giménez et al., 2015; Tachiiri and Shinoda, 2012; J. Wang et al., 2013; Y. Wang et al., 2013).

The effects of snow disaster on livestock involve a complex interaction between precipitation, vegetation, livestock, and herder communities (Shang et al., 2012). In addition to the direct stress caused by snowfall and snow cover, strong winds, and low temperatures are also believed as critical stressors during the disaster (Wu et al., 2007). Moreover, a dry summer could substantially reduce grassland productivity and consequently lead to poor livestock body reserves, which is crucial for animals to resist starvation and endure the cold (Wang et al., 2014). Large herd sizes, nomadic grazing, and lack of infrastructure also contribute to high livestock snow disaster losses (Yeh et al., 2014).

In response to the threat of livestock snow disasters, efforts have been made to understand the major environmental, biophysical, socioeconomic, and policy factors/drivers contributing to livestock loss. Earlier studies focused on qualitative/semi-quantitative linkages of factors to snow disaster losses to develop early-warning systems (J. Wang et al., 2013; Y. Wang et al., 2013) and ordinal risk assessment (Li et al., 2014; Liu et al., 2014; Wu et al., 2007). With the evolving need of early-warning systems, insurance and other risk-transfer solutions, and risk-based climate change adaptation actions, researchers as well as practitioners have increasingly realized the necessity of quantifying the relationship among livestock loss, snow hazard intensity, and other environmental stressors. For example, Tachiiri et al. (2008) were the first to introduce remote sensing snow and vegetation indices into quantitative estimations. They have also pointed out the necessity of considering non-linear models. However, their results suffered from large cross-validation errors due to the lack of data and consideration of environmental stressors other than snow. Two recent works in the Tibetan region obtained favorable goodness-of-fit by incorporating related biophysical and socioeconomic factors into the estimation (Fang et al., 2016; Wang et al., 2016). However, their list of explanatory variables can only be supported with detailed historical data in small local areas, which also limits the applicability of their model to a larger spatial extent. Moreover, they have all focused on annual loss rather than event-based loss, which is actually more important for disaster early-warning and risk-transfer arrangements. Analyses for larger spatial regions with reasonable predicting power are still needed.

The present article intends to quantify the linkage of livestock mortality to snow hazards and other environmental stressors in the Qinghai-Tibetan Plateau (QTP) region. The QTP has the highest natural pastoral area in the world, with a total grassland area of 1.57 $\times$ 10^6 km^2, representing 1/3 of the grassland area in China (Zhao et al., 2013). It supports the grazing of ca. 38 million livestock (2014), and the livelihood of 2 million pastoralists and 3 million agro-pastoralists (Miller, 2005). Large variation in summer and winter precipitation, nomadic grazing, and lack of infrastructure all makes this region extremely prone to livestock snow disaster (Wang et al., 2014). The QTP is also the most sensitive area to global climate change (Liu and Chen, 2000). A clear warming trend and increased precipitation have been detected in recent years, and yet the trend has been predicted to continue well into future decades (Gao et al., 2016), thus leading to higher frequency and intensity of snow hazards (Wang et al., 2016). Therefore, quantification of the relationship between livestock mortality and environmental stress in snow disasters is of great importance for disaster risk reduction and climate change adaptation for the QTP.

The aim of this study is two-fold: 1) to understand the linkage among livestock mortality, snow hazard intensity, and other environmental stressors, and 2) to establish a quantitative model for prediction of livestock mortality in the QTP region. To fulfill these goals, this study sets up a wide-spatial extent, a long-time series, and an event-based livestock snow disaster dataset, trying to cover the entire QTP rather than looking at local prefectures/counties. In addition, efforts were made to use as many historical event loss datasets as possible yet without sacrificing the number of factors. The Generalized Additive Model (GAM), which has shown great potential and flexibility in addressing non-linear relationships (Hastie and Tibshirani, 1986) was used in this study. The derived relationship can support quantitative probabilistic risk assessment, and then support risk-based decisions in prevention, mitigation, and climate change adaptation actions.

2. Materials and methods

2.1. Study area

The QTP is located in Southwest China (26°00′N ~ 39°47′N, 73°19′E ~ 104°47′E; Fig. 1). It has an area of 2.572 $\times$ 10^6 km^2, accounting for 26.8% of the total land area in China. The region consists of 210 counties from Tibet, Qinghai, Sichuan, Gansu, Xinjiang, and Yunnan provinces/autonomous regions (Zhang et al., 2002). The terrain decreases from northwest to southeast, with an average elevation of 4000–5000 m. The climate in this region is mainly continental, dominated by great diurnal but small annual variations in temperature. Summers are characterized by higher precipitation whereas winters are dry and cold with strong winds.

The QTP has extremely rich grassland resources. The land used for farming and raising livestock is approximately 1.63 $\times$ 10^6 km^2, of which alpine grassland covers an area of 1.57 $\times$ 10^6 km^2 (Zhao et al., 2013). The rich grassland resources support one of the largest animal husbandry production bases in China. In 2014, the QTP housed a total of 38.03 million livestock, among which 10.47 million were cattle, and 26.47 million were sheep (Qinghai Provincial SB, 2015; Tibet Autonomous Region SB, 2015). This region supports the livelihood of approximately 2 million pastoralists and 3 million agro-pastoralists (Miller, 2005). Animal husbandry production in 2014 reached 23.85 billion RMB yuan,[1] with 9.25 billion Yuan for cattle, and 7.4 billion Yuan for sheep and goats. For centuries, raising livestock has been the most important way to survive and make a living for local herder communities in the QTP. Farming livestock is the critical means of obtaining daily dairy and meat consumption by local herdsmen, rather than serving as a major income source as in Inner Mongolia. Nomadic or semi-nomadic way of grazing has succeeded for hundreds of years for centuries (Wang et al., 2014), and is difficult to change in a short period of

[1] 1 yuan = 0.151 USD as of Oct 24, 2017.