Forest fuel characteristics and the impacts of climate change on forest fires in southeast Tibet [1]

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Abstract

The distribution of forest fuel is very important to the occurrence of forest fires. This paper used DEM data and vegetation distribution map to analysis the horizontal and vertical distribution of forest fuel, and calculated the fire circle and fire probability based on the fire history data as well. The tendency of fire occurrence was analyzed from the precipitation and air temperature records. This region locates in high altitude area, the ecosystem is fragile, the forest volume is large, and the potential fire intensity is very high. The growing tendency of temperature in recent years impel fire danger rating to rise quickly, the impact of temperature rising is more severe on high altitude area than on low altitude area, and the fire danger rating situation of high altitude area is more severe.

1 Introduction

Forest fire is one of the main factors that disturb the forest ecosystem markedly[1,2]. 350~400 million years ago, the earth already had the condition of forest fires. The occurrence of forest fires directly lead to the change of the proportions of the oxygen and carbon dioxide in the atmosphere with carbon dioxide increasing and greenhouse effects strengthening. Forest fires are sensitive to climate changes. In recent years, climatic anomalies arise, temperature rises, hurricanes are frequent, and it is severely arid, all of these are rare in the world history. Including China, the world is experiencing a great climatic change course whose main characteristic is climate warming. Climatic anomalies and forest structure changes have combined, and forest fire seasons have changed evidently, and fire occurrence has exhibited a tendency to increasing [3,4].

Global climate change influences the precipitation distribution and temperature variation in different regions, and then impacts the vegetation distribution. Global warming would lead to changes in the amount and decomposition of litters, and it would cause changes in vegetation distributions, phenology characteristics, and litter decomposition confines, and it would influence the regime of forest litters, and ultimately it would influence the function of forest ecosystem material cycle [5]. To a certain extent, global climate changes have influenced the distribution of natural and human fire causes, the forest fuel spatial distribution and flammability of fuel. Due to a necessary continuous accumulation of fuel and energy releasing rapidly once ignited [6,7], forest fires always exhibit periodicity. The results of Zhao Maosheng et al. (2002) show that future climate changes might cause the east forest vegetation of China to move north, and the area of north deciduous forest would reduce sharply.

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The same situation takes place at the area of high altitudes. Due to climate changes, forest line and vegetation distribution consequently have changed, which have influenced the characteristics and structures of forest fuel[8]. On a global scale, forest fires are important disturbance factors, which influence the bio-chemical cycle of the earth, and play an important role in the chemical and carbon cycle of the atmosphere[9]. In many cases, forest fires have already become a part of the ecosystem, and dominant tree species have adapted to fire cycle.

Southeast Tibet forest is the important virgin forest in China, and it is also the region where forest fires occur frequently. There are few studies on the influences of temperature and precipitation changes on forest fires at the area of high altitudes. The present study attempted to initial analyze the southeast Tibet forest fires from forest fuel distribution, forest fire history, temperature and precipitation respects.

2 Study Area

Southeast Tibet forest (Linzhi) (92˚9′ ~98˚18′E, 27˚33′~30˚40′N), is the main area of Tibet virgin forests, and the principal part of southwest national forests. Because of special topography, geomorphology, climate and etc, Tibet forests have special tree species composition and intact vertical distribution. The main forest types are as follows: subalpine dark coniferous forest, temperate mountain pine forest, temperate sclerophyllous evergreen robur forest, mountain deciduous broad-leaved forest, mountain cypress forest, etc.

Linzhi is located at the mean altitude of 3100 m, and mountains in it are all in east-west direction. North is high, south is low, and the altitude difference between north and south is great. Annual precipitation is approximately 650mm, annual mean temperature is 8.7℃, annual sunshine time is about 2022.2 h, and annual frost-free days are 180d. Mean temperature in winter is above 0℃, mean temperature in summer is 20℃, and four seasons are distinct from each other. The natural environment of the region is unique, influenced by southwest monsoon. Forests in the region are over mature forest, in which the proportion of trees infected with disease, rotten-wood, and dead standing account for much. Forest ecosystem is frail, and it is very extremely difficult to restore once destructed by forest fires. Fire sources are complex, and climate in the region is unique. High Fuel accumulation and high altitudes form special local fire environment. It is very difficult to prevent and fight fires in the region.

3 Materials and methods

3.1 Fuel types

The vegetation distribution maps of Linzhi (1:1000000) were digitized by ARCGIS9.1, and were overlaid on DEM data (1:250000). The vegetations were classified into different types by fuel flammability. Horizontal and vertical distributions of vegetation types were calculated. At last, different vegetation types were classified into seven forest fuel types by vegetation flammability and fires of a certain vegetation type in history. The seven forest fuel types of the region are as follows: Alpine pine and Yunnan pine forest, spruce and fir forest, meadow bush, broad-leaved forest, meadow steppe, bush, Yunnan hemlock forest.

3.2 Fire cycle

Fire cycle is the number of years required to burn over an area equal to the entire area of interest. It is an index to describe the interval between two successive fires. It can be expressed by the formula beneath.

$$FC = \frac{S}{S_a} \qquad (1)$$

Where FC, S , Sa are fire cycle, the area of study site and annual mean burned area respectively, and the units of them are a, ha, ha respectively。

3.3Fire probability

Fire probability is an index expressing the likelihood that fire will occur, it is related to fire cycle, and it can be expressed by the formula beneath.

$$P(t) = 1 - e^{-1/FC} \qquad (2)$$

Where FC, P are fire cycle and initial fire probability respectively.

4Fuel distributions

4.1 Horizontal distribution of fuel

Forest fires are closely related to vegetation. The common flammable forest types are as follows: herb, fern, and Alpine Pine forest; herb, fern, and Yunnan Pine forest; herb, fern, Alpine Pine and Yunnan Pine mixed forest; herb, Alpine Pine and spruce mixed forest; arrow bamboo (*Fargesia*) , bush, and Alpine Pine forest; arrow bamboo, bush, Yunnan Pine forest. The common fuel is litter, the dry bark, the cone, seasonal withered plants (herb, brush, ferns, and tree moss), the fallen trunk, the stump, the dry standing timber, and forest residue etc.

Alpine Pine (*Pinus densata*) and Yunnan Pine (*Pinus yunnanensis*) forests approximately occupy 148053 ha and 5080ha respectively. The sum of them accounts for 1.35% of the total area. The forests are mainly located at Linzhi, Milin, along Brahmaputra, and they are the main area with a high incidence of forest fires. There are a few distributions of Alpine Pine and Yunnan Pine forests in Pomi (Fig.1). Due to dense population, roads being built along the river and being through Alpine Pine forests, human fire causes increase markedly.

Being located at high altitudes and it is arid in winter and spring, the Alpine pine forests are forests with a high incidence of fires in China. With a formal appearance, the species composition of Alpine pine forest is simple, occasionally mixed with poplar, birch and Alpine robur. The forest always is uneven aged forest formed by the single dominant tree species----Alpine pine, and the proportion of mixed species does not arrive at 20%. The species of community are abundant, however, the structure of community is simple and layers of community are distinct from each other. On the cut-over land of spruce and fir forests, there are natural regenerated seedlings of Alpine pine. Especially in burned area, the natural regenerated seedlings of Alpine pine grow well. According to the tendency of forest succession, within a certain period, Alpine pine has natural advantages in the whole drainage area.

Alpine pine is shade species, which contains plentiful flammable materials, such as rosin, volatile matters, etc. Generally, alpine pine forest is uniform even-aged pure forest with a small crown density. The temperature in the forest is high and the humidity is low. Especially in long winter, few precipitation, strong sunshine and great evaporation lead forest land to aridity and reduce the ignition temperature of

flammable fuel, and ultimately enhance the fire danger rating of the forest. The forest will burn rapidly once ignited in a situation of high temperature, low humidity and strong wind. So the fires are very difficult to suppress. In a word, the fire danger rating of Alpine pine forest is high because of arid forest land, plentiful flammable fuels, and Alpine pine being flammable itself. The positive and effective measurements should be carried out to prevent the forest fires.

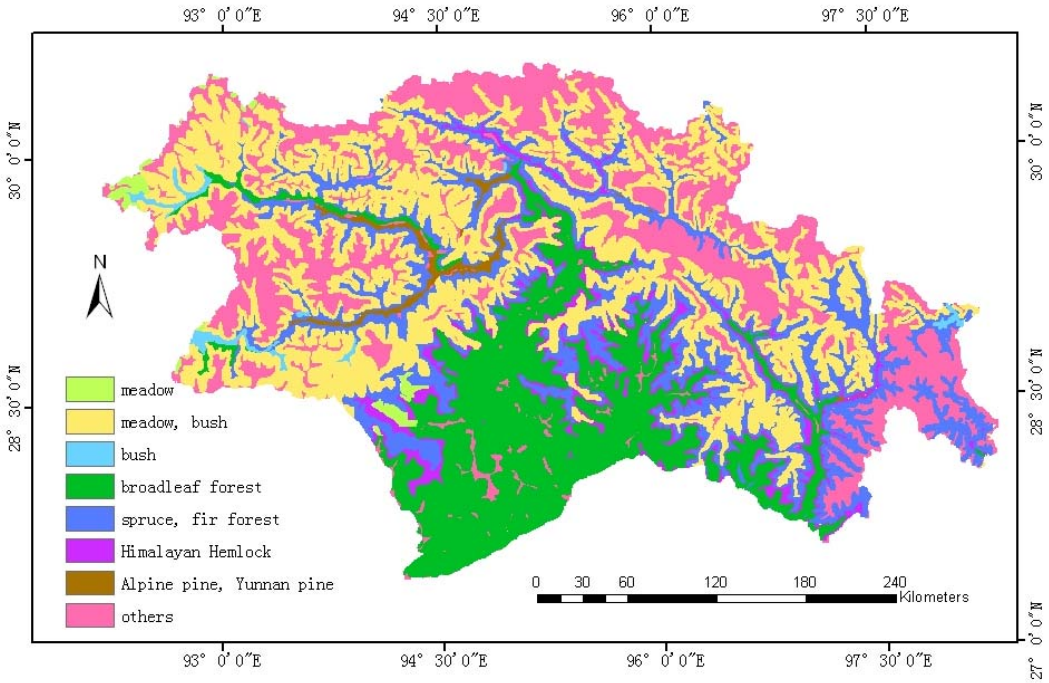


Figure 1— Distribution of different fuel type

Meadow and bush is the area with a high incidence of forest fires too. It approximately occupies 2959469ha, accounts for 26.01% of the total area. Severe forest fires may occur in dry season in spruce and fir forests and broad-leaved forests, which occupy 2010065ha and 2081273ha respectively, account for 17.67% and 18.29% of the total area.

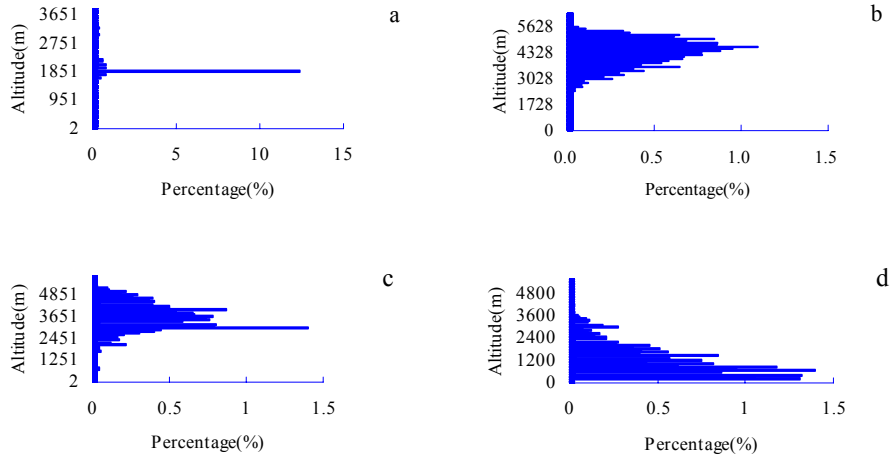
4.2Vertical distribution of fuel

The areas of different fuel types at different altitudes are calculated using different vegetation types and DEM data. The percentages (%) of a certain fuel type area at different altitudes accounting for the total area of the certain fuel type are calculated also (Fig.2).

Because of small area of meadow steppe, bush, and few forest fires in Yunnan hemlock forests, these three vegetation types have not been analyzed. The distribution centre of Alpine pine and Yunnan pine forests is at the altitude of 1900m (Fig.2a), and the distributions of them are concentrated. At the altitude range of 2800~3600m, the Alpine pine forests naturally regenerate very well in burned area. But above the altitude of 4000m, with few species of shrub and grass, low coverage, and severe habitat, there is no Alpine pine seedlings regeneration in burned area. Due to large humidity, Alpine pine as well as shrub and grass regenerate better on the semi-shady slope than on the arid sunny slope.

Meadow and bush is an important forest fuel type. Its distribution centre is at the altitude of 4600m, and it sketches into high and low altitudes (Fig 2b). The forest fires always are surface fires. But with strong wind and arid weather, crown fires may occur at the joint areas with Alpine pine and Yunnan pine forests, spruce and fir forests, which always are the initial areas of forest fires. In meadow and bush, broad-leaved forests are mostly located at the area with a relative low altitude.

Spruce and fir forests are located at the area with a relative high altitudes, their distribution centre is at the altitude of 3400m (Fig.2c). Sometimes forest fires spread in the humus, they can evolve into ground fires due to great amount of litters and deep humus. There are two peaks of litters in a year, one is at the beginning of rainy season (Apr. and May), the other is at the end of the rainy season (Sep. and Oct.). The lowest amount of litters is in the dry season (Nov., Dec., Jan., and Feb.) [10]. Because of plentiful rosin in the litters, the burning speed is fast, and the fires are very difficult to suppress. It can be shown from Fig.2d, broad-leaved forests are mainly located at the area below the altitude of 3600m, and their distribution centre is at the altitude of 700m. Broad-leaved forests may occur fires in the very arid year.



a. Alpine pine, Yunnan pine forest b. meadow, bush

c. spruce, fir forest d. broad-leaved forest

Figure 2— Distribution of fuels in different altitude and the percentage of them

4.3Fire probability and fire cycle

In the calculation of fire cycle, only the defined area is taken into account, that is to say, fire cycle is the number of years required to burn over the entire covered area of fuel. Fire cycle and fire probability are 17178a and 0.00006 respectively according to the formula (1) and (2). Because of the particularity of the area, with high altitudes, fragile ecosystem, large forest storage capacity, and great accumulated energy, though the fire probability is very low, but the potential fire intensity is high and ecosystem is very difficult to restore after fires.

Despite long fire cycle, the corresponding fire probability is small. Whether the small probability is the inherent nature of the region or is caused by outside or human disturbances still need further study. To analyze inherent fire cycle and fire

probability, and then to control fire occurrence at a proper level is significant to maintain the stability of ecosystem.

4.4Impacts of climate changes on forest fires in the future

According to forest fire records, the period from Nov. to next May is the important fire season in the region. In Tibet, the forest fire prevention period is from Nov., 1 to next May, 30, and the period with a high incidence of fires is from Feb. to May, especially in Mar. to Apr. [12].

The results show (Chouduo *et al.,* 2003) that the variation tendency of monthly mean NDVI and monthly precipitation are similar, that is to say, they all have high value in summer and low value in winter and spring. The lowest monthly mean NDVI is in Feb. and March. In Feb., vegetation is in dormant. In June, vegetation begins to grow and the value of NDVI increases rapidly due to the coming of rain season [13]. Forest fire records and the changes of NDVI all indicate that the period from Feb. to May is the dormancy stage of vegetation, because of low fuel moisture content, it is also a period with a high incidence of forest fires.

According to forest fires records and NDVI, the monthly meteorological data of Linzhi (from Jan. of 1962 to Dec. of 2001), Chayu (from Feb. of 1966 to Dec. of 2001), Pomi (from Jan. of 1962 to Dec. of 2001) and Milin (from Jan. of 1998 to Dec. of 2001) are used to calculate the mean temperature and precipitation of the period with a high incidence of fires (Feb. to May) in order to compare changes among years (Fig. 4).

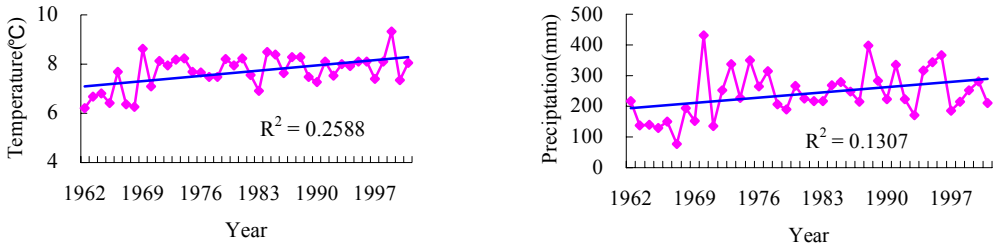


Figure 3— The mean temperature and precipitation from Feb to May in Linzhi (1962~2001)

As shown in Fig.3, in recent 40 years there is a slowly rising tendency of temperature and precipitation in the region, which influence the structure and distribution of forest fuel at a certain extent. The rising tendencies of seasonal and annual mean temperature are that the temperature have risen more in high altitudes than in low altitudes. Especially in the area above the altitude of 4000m, the temperature have risen most (Du Jun *et al.*, 2001). The rising tendency of temperature was weak in summer than in other three seasons, and temperature has risen most in autumn. In Tibet altiplano, annual mean temperature has risen with a ratio of 0.26℃/10a in last 40 years, which was markedly higher than the ratio of China and the whole world[14].

Zhou Shunwu *et al*. (2001) have studied the precipitation along Brahmaputra. It was shown that the precipitation in summer exhibited a downward trend. The annual precipitation was relative little during the middle and later periods of 60s to the end of the 80s, and it has presented an upward trend since 90s [15].

In the region, the precipitation has decreased in summer, however, the precipitation during the period with a high incidence of fires (Feb. to May) has increased to some extent. But the temperature of the region has risen markedly. The impacts of temperature rising on the area with high altitudes are larger than on the area with low altitudes. As to forest fuel, the impacts of temperature rising on the forest fire danger at the area with high altitudes are great, which cause a more severe situation of forest fire prevention.

5 Conclusion and discussion

The main flammable fuel types in southeast Tibet forest are Alpine pine and Yunnan pine forest, spruce and fir forest, meadow and bush, etc. Alpine Pine and Yunnan Pine forests approximately occupy 153133ha, account for 1.35% of the total area, which are mainly located at Linzhi, Milin. This kind of forest fuel type is along Brahmaputra, and it is the main forest with a high incidence of forest fires. There are a few distributions of Alpine Pine and Yunnan Pine forest in Pomi. The distribution centre of Alpine pine and Yunnan pine forests is at the altitude of 1900m, and the distributions of them are concentrated. At the altitude range of 2800~3600m, the Alpine pine forests naturally regenerate very well in burned area. But above the altitude of 4000m, with few species of shrub and grass, low coverage, and severe habitat, there is no Alpine pine seedlings regeneration in burned area. Due to large humidity, Alpine pine as well as shrub and grass regenerate better on the semi-shady slope than on the arid sunny slope.

Spruce and fir forests are located at the area with relative high altitudes, which occupy 2010065ha, account for 17.67% of the total area, and concentrate at the altitude of 3400m. Due to great amount of litters and deep humus, when forest fires spread in the humus, they can evolve into ground fires.

Meadow and bush is an important forest fuel type. Its distribution centre is at the altitude of 4600m, and it stretches to the area with high and low altitudes. Meadow and bush occupies 2959469ha, accounts for 26.01% of the total area.The forest fires always are surface fires. The joint areas with Alpine pine and Yunnan pine forest, spruce and fir forest are often the initial area of forest fires.

In the region, most broad-leaved forests are located at the area with relative low altitudes, which occupy 2081273ha, account for 18.29% of the total area. The forests are mainly located at the area below the altitude of 3600m, and concentrates at the altitude of 700m.

The fire cycle and the fire probability of the region are 17178a and 0.00006 respectively. Because of the particularity of the area, with high altitudes, fragile ecosystem, large forest storage capacity, and great accumulated energy, though the fire probability is very low, the potential fire intensity is high and ecosystem is very difficult to restore after fires.

In the region, the precipitation has decreased in summer, however, the precipitation during the period with a high incidence of fires (Feb. to May) has increased to some extent. The temperature of the region has risen markedly. The impacts of temperature rising on the area with high altitudes are larger than on the area with low altitudes. As to forest fuel, the impacts of temperature rising on the forest fire danger at the area with high altitudes are great, which cause a more severe situation of forest fire prevention.

In the past 50 years, because of the influence of fire prevention and suppression, forest fire frequency has decreased significantly. But the probability of large forest fires has increased to some extent due to the accumulation of forest fuel.

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