Transformation of the vegetation of the Tsasuchey steppe pine forest

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Abstract. The Tsasuchey pine forest is located at the South-Eastern Trans-Baikal near the Mongolian border. This territory is included in the State Nature Reserve of Federal Importance “Tsasuchey pine forest”. An increase in air temperatures and a low atmospheric precipitation in recent decades resulted in an increase in fire hazard and catastrophic fires, which nearly destroyed the pine forest. With the help of satellite images of the Terra/Modis spectroradiometer, we determined the burnt areas and vegetation indices NDVI and EVI for the territory of Tsasuchey pine forest. The research results showed that the fires are the key factor of vegetation transformation at the forest territory, and its recovering is closely connected with humidifying. During the last drought period the pine forest area was reduced from 43.5 to 2.5 thousand ha as the result of the catastrophic fires in 2000, 2003, and 2012. Correlation coefficients between investigated vegetation indexes on the territory of Tsasuchey pine forest and meteorological factors show the proved connection between precipitation and hydrothermal index (humidity factor), herewith, the EVI shows higher correlation coefficients with meteorological parameters than NDVI, which indicates its high informative value. The most direct relationship was revealed between the average and maximum monthly values of the EVI index and the total precipitation. In the dynamics of the average annual minimum values of EVI, there is, on average, a positive trend, which indicates an increase in the amount of vegetation on the territory of Tsasuchey pine forest during the warm period.

1. Introduction

According to IPCC estimates, there is no doubt that the world became warmer in comparison with 21st century. Intergovernmental Panel on Climate Change informs on warming by 0.87°C in 2006-2015 [1]. Vegetation cover as an indicator responsive to the climatic changes is transformable against the background of the observed tendencies [2]. The vegetation cover transformation represented as dynamics of photosynthetically active biomass are well-correlated with spectral vegetation indices [3-5]. The vegetation index is an indicator that is a combination of various spectral channels of radiation reflected from vegetation cover or other surfaces, calculated from remote sensing data. The temporal series of vegetation indices received from the Earth remote sensing data proved their efficiency in monitoring of long-term variability of terrestrial ecosystems [6], of global, continental and regional scale, because vegetation indices (in particular, NDVI and EVI) provide valuable information on properties of geological substate with different level of detail. The Tsasuchey steppe pine forest is located in the southeastern Transbaikalia near the state border of the Russian Federation and Mongolia. The forest is included in the territory of Daursky State Natural Biosphere Reserve as the
State Natural Reserve of Federal Importance Tsasuchey pine forest. Land boundary survey in 2010 has shown that the area of the reserve is 58881 hectares [7]. The vegetation of the pine forest is regularly affected by fires.

From 1976 to 2018, the average annual air temperature growth in the study area averaged 0.35°C/10 years (the trend is statistically valid). As for moisture regime, it shows cyclical alteration of wet and dry periods approximately 30 years long. Currently a water-abundant phase of the cycle is observed; it was preceded by 13-year-long low-flow period (1999-2011) [8].

These factors resulted in disastrous fires which actually destroyed the Tsasuchey pine forest [9].

2. Materials and methods

Areas of the Tsasuchey reserve covered by forest was determined for the period from 1986 to 2018 on the basis of high-resolution satellite images (30 m) Landsat TM, ETM+ and OLI (http://reverb.echo.nasa.gov/) in ArcGIS-10 software. Areas influenced by fires were estimated by MCD45A1 product of Modis software collection. This product is based on Terra and Aqua satellite images after atmospheric correction available in NASA LP DAAC data center (https://lpdaac.usgs.gov/). Spatial resolution of the product composite is 500 m; time interval is 1 month.

NDVI and EVI vegetation indices describing changes in vegetation cover were determined for the period from 2000 to 2018 for 39 points of the Tsasuchey pine forest by 4.6 x 6 km grid. Terra/MODIS spectral radiometer satellite images taken from May to September were used as initial data for Earth remote sensing. The Land Processes Distributed Active Archive Center (NASA LP DAAC) MOD13A2 preprocessed freeware product (Vegetation Indices 16-Days L3 Global 1 km) was used for the analysis. MOD13A2 product (version 6) contains two basic vegetation layers: normalized difference vegetation index (NDVI) and enhanced vegetation index (EVI) and provides data on spatial distribution of vegetation indices values with ground resolution of 1 km and periodicity of 16 days. The materials of MOD13A2 cover time interval of 16 days; therefore initial values of vegetation indices were interpolated to daily values, reduced to average monthly values within the timeframe of research period and afterwards were assumed as reference values. The NDVI and EVI indices take values from -1 to 1. Negative values of the indices correspond to objects of non-plant origin, positive values over 0.2 – to vegetation. The higher the index value, the higher the photosynthetic active biomass value in the area under study.

To assess the long-term changes in the vegetation indices for the warm period of the year, we analyzed the time series of monthly mean values, as well as the extreme characteristics of the period under study, showing the maximum and minimum degrees of plant development. A correlation analysis was performed concerning the values of vegetation indices and climatic parameters (air temperature, total precipitation, humidity factor, Selyaninov hydrothermal moisture coefficient, and Ped’ aridity index), averaged according to the observation data of four meteorological stations of the Transbaikal Directorate for Hydrometeorology and Environmental Monitoring (Aksha, Borzya, Nizhny Tsasuchei and Solovievsk), located near the study area to identify the response of vegetation to changes in weather and climatic conditions.

3. Results and discussion

Analysis of the integral curve of average annual precipitation amounts over the territory since 1950 makes it possible to distinguish two wet phases in the atmospheric precipitation regime: 1956-1970 and 1983-1998 – and two dry: 1971-1982 and 1999-2011. At the same time, on the integral difference curve of average annual air temperatures across the territory, there are two periods of increase in average annual air temperature (1958-1975 and 1989-2008) and one period of its decline (1976-1988).

According to the data of Earth remote sensing for 2000-2014, forest fires in 2000, 2003 and 2012 (table 1) were the most intensive and massive within the territory of the Tsasuchey pine forest. Totally the fires destroyed 96.2 % of the Tsasuchey pine forest territory over the period of research (figure 1).
Table 1. Fire burnt areas within the territory of the Tsasuchey pine forest (2000-2014) according to MCD45A1 data.

| Years | Area, thou ha | Years | Area, thou ha |
|-------|---------------|-------|---------------|
| 2000  | 28.10         | 2009  | 1.20          |
| 2003  | 19.70         | 2010  | 0.20          |
| 2004  | 1.20          | 2011  | 0.20          |
| 2006  | 2.10          | 2012  | 20.22         |
| 2007  | 0.02          | 2014  | 1.50          |
| 2008  | 0.50          |       |               |

This led to the fact that the forested area of the pine forest decreased by 94% during the period under study. Before the last dry phase of the humidification cycle (1999-2011), the area of the pine forest was more than 40 thousand hectares, after the fires in 2000 the area of the pine forest decreased to 21.3 thousand hectares, and after the 2003 fires - up to 7.9 thousand ha. The forest fire in April 2012 destroyed almost all of the remaining plantings. Thus, as a result of the catastrophic fires that occurred in Tsasuchey pine forest since 2000, by 2012 only 2.5 thousand hectares of forest land remained. This is less than 6% of its area at the beginning of the last dry phase of the cycle, which began in 1999.

Figure 1. Fire burnt area (1) within the territory of the Tsasuchey pine forest (2) (2000-2014) according to MCD45A1 data.

Analysis of seasonal dynamics of vegetation indices shows that in average over the period of research the least values are peculiar for May and amount to 0.30 and 0.15 for NDVI and EVI correspondingly. In June gradual growth of vegetation indices is observed (NDVI=0.42; EVI=0.21). The maximum long-term annual average values of vegetation indices are observed in July (NDVI=0.52; EVI=0.26) and August (NDVI=0.53; EVI=0.26). For September decreased vegetation activity is peculiar; average values of NDVI and EVI indices fall to 0.42 and 0.19 correspondingly (table 2).
Such dynamics can be explained by accumulation of chlorophyll in summer period and decrease of its total quantity in the beginning and in the end of vegetation period.

It has to be noted that seasonal variations of EVI index values show the similar pattern with seasonal variations of NDVI (figure 2). Correlation analysis between average monthly values of NDVI and EVI during the warm period of the year within the territory of the Tsasuchey pine forest has shown their close significant relation ($r=0.95$).

### Table 2. Values of NDVI and EVI indices by months within the territory of the Tsasuchey pine forest in 2000-2018.

| Month   | NDVI | EVI |
|---------|------|-----|
|         | Average long-term value | Maximum / Year | Minimum / Year | Average long-term value | Maximum / Year | Minimum / Year |
| May     | 0.30 | 0.60/2002 | 0.17/2003 | 0.15 | 0.27/2002 | 0.06/2000 |
| June    | 0.42 | 0.67/2002 | 0.25/2003 | 0.21 | 0.32/2006 | 0.07/2000 |
| July    | 0.52 | 0.76/2002 | 0.28/2007 | 0.26 | 0.42/2012 | 0.09/2003 |
| August  | 0.53 | 0.73/2002 | 0.33/2000 | 0.26 | 0.38/2011 | 0.11/2003 |
| September | 0.42 | 0.69/2002 | 0.28/2006 | 0.19 | 0.28/2002 | 0.10/2003 |

The results of analysis of images have shown that the NDVI image reflects the largest share of dark-green spectral range, because NDVI loses sensibility to changes in vegetation in areas with higher density of biomass (forests in this case). EVI image is characterized by more stable sensitivity to changes in vegetation and more even distribution of vegetation indices.
The amplitude describing annual variation of vegetation indices is the evidence of considerable changes of NDVI and EVI over the period of research. The least annual amplitude of both NDVI and EVI is observed in 2016 (0.32 and 0.14 correspondingly). The maximum variations of NDVI with amplitude of 0.51 were registered in 2002, EVI – in 2012 (0.34). At that average annual values of NDVI were ranging from 0.37 (2007) to 0.52 (2002) and in average amounted to 0.44. EVI was ranging from 0.17 (2003) to 0.25 (2018); in average it amounted to 0.21.

Correlation analysis of vegetation indices and the climate of the territory show certain relations (table 3). Significant positive correlations were noted with vegetation indices and atmospheric precipitation, as well as with hydrothermal moisture coefficient; a significant negative correlation was also noted for the EVI and Ped’ aridity index. A direct significant relationship with air temperature was found only for the minimum NDVI values.

**Table 3.** Coefficients of correlation between the studied vegetation indices within the territory of the Tsasuchey pine forest and meteorological parameters.

| Meteorological parameter | Average NDVI | Average EVI | Maximum NDVI | Maximum EVI | Minimum NDVI | Minimum EVI |
|--------------------------|--------------|-------------|--------------|-------------|--------------|-------------|
| Air temperature          | 0.12         | -0.10       | -0.01        | -0.29       | 0.46         | -0.03       |
| Precipitation            | 0.51         | 0.76        | 0.46         | 0.76        | 0.17         | 0.29        |
| Hydrothermal moisture coefficient | 0.43 | 0.69 | 0.44 | 0.73 | 0.03 | 0.24 |
| Ped’ aridity index       | -0.18        | -0.44       | -0.21        | -0.52       | 0.22         | -0.20       |

* Significant coefficients are marked in bold (p <0.05).

The maximum direct correlation was determined between average monthly values of EVI index and total precipitation fallen over the warm period of the studied time sequence (r=0.76) (figure 3).

**Figure 3.** Dynamics of average annual values of EVI and total precipitation of the warm period.
The correlation analysis has determined close inverse relationship between minimum annual values of EVI and fire burnt areas ($r=-0.87$) (figure 4). In years of massive fires vegetation indices values sharply decreased to 0.06 (2000) and 0.08 (2003, 2012). Over the period after fires vegetation indices grow, which is caused by subsequent regeneration of vegetation.

**Figure 4.** Dynamics of the minimum average annual EVI values and fire burnt areas within the territory of the Tsasuchey pine forest.

In average positive trend can be traced in dynamics of the minimum average annual EVI values which testify of increased vegetation volume within the territory of the Tsasuchey pine forest over the warm period (figure 5).

**Figure 5.** Dynamics of the minimum average annual EVI values within the territory of the Tsasuchey pine forest.
Assessment of the response of vegetation to the impact of fires based on the analysis of vegetation indicators in the Tsasuchei pine forest showed that areas that are not exposed to fires for a long time have the ability to restore vegetation cover. At the same time, the results of field studies carried out on the territory of the pine forest indicate that mainly aspen-forb and forb communities develop on its burned-out areas [10]. The renewal of pine undergrowth with young undergrowth was noted in most of the communities affected by the fire, however, due to repeated fires, pine undergrowth older than 5 years is practically not preserved.

4. Conclusion
The results of the research showed that the fires are the key factor of vegetation transformation at the territory of Tsasuchey pine forest, and its recovering is closely connected with humidifying of the territory. During the last drought period (from 1999 to 2012) Pine forest area was reduced from 43.5 to 2.5 thousand ha as the result of the catastrophic fires in 2000 (28.1 thou ha), in 2003 (19.7 thou ha), in 2012 (20.2 thou ha). Correlation coefficients between investigated vegetation indexes on the territory of Tsasuchey pine forest and meteorological factors show the proved connection with amount of precipitation and hydrothermal moisture coefficient, herewith, the EVI shows higher correlation coefficients with meteorological parameters than NDVI, which indicates its high informative value. The greatest direct connection between medium and maximum values of EVI index and precipitation amount (r = 0.76) is revealed. At the average, in the dynamic of EVI annual minimum mean values the positive trend is observed which shows the increase of the vegetation on the territory of Tsasuchey pine forest in the warm period of research.

Acknowledgements
Satellite images were prepared within the framework of the basic project, the calculation of the dryness and humidity indexes was performed within the Russian Science Foundation support (Project No.19-14-00028).

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