Simulating the Effects of Fire on Forests in the Russian Far East: Integrating a Fire Danger Model and the FAREAST Forest Growth Model Across a Complex Endangered Wildlife Habitat

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Introduction

The remaining natural habitat of the critically endangered Amur tiger (*Panthera tigris altaica*) and Amur leopard (*Panthera pardus orientalis*) is a vast, biologically and topographically diverse area in the Russian Far East (RFE). Although wildland fire is a natural component of ecosystem functioning in the RFE, severe or repeated fires frequently re-set the process of forest succession, which may take centuries to return the affected forests to the pre-fire state and thus significantly alters habitat quality and long-term availability. The frequency of severe fire events has increased over the last 25 years, leading to irreversible modifications of some parts of the species' habitats. Moreover, fire regimes are expected to continue to change toward more frequent and severe events under the influence of climate change. Here we present an approach to developing capabilities for a comprehensive assessment of potential Amur tiger and leopard habitat availability throughout the 21st century by integrating regionally parameterized fire danger and forest growth models. This work presents the first attempt to merge the FAREAST model with a fire disturbance model, to validate its outputs across a large region, and to compare it to remotely-sensed data products as well as in situ assessments of forest structure.

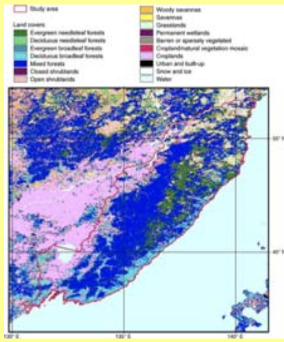

Fig. 1. *Land covers of study area (MODIS land cover product: IGBP classification). Loboda & Csiszar, 2007*

Fig. 2. *Amur tiger present and potential habitat. Graphic: Wildlife Conservation Society*

Impact of Fire on Wildlife Habitat

Approximately 330-390 mature Amur tigers (Miquelle *et al* 2006) and about 30 Amur leopards (WCS 2006) exist in the wild (Figs. 3 - 4). Principle threats are inadequate prey, poaching, and loss of habitat from logging and development. Amur leopards are particularly vulnerable to loss of habitat from repeated human-caused fires, which convert forests to open grasslands (Figs. 7&8). Non-recurring, low intensity fires can improve habitat by clearing underbrush and nourishing soil, but severe or repeated fires can re-set the process of forest succession. In the case of extremely severe or repeated fires, the original forest may take centuries to re-grow.

The primary prey of tigers are wild boar (*Sus scrofa*), red deer (*Cervus elaphus*), sika deer (*C. nippon*), and roe deer (*Capreolus pygargus*). The existence of these ungulates is related to forest type: they depend on the nuts, cones and leaves of Korean pine (*Pinus koraiensis*) and Mongolian oak (*Quercus mongolica*), as well as a variety of shrubs and grasses, and avoid larch and spruce-fir forests (Stephens *et al* 2006).

Figs 3 – 4. *Amur tigers & Amur leopard in Primorskiy Krai, Russia, photographed by infrared motion-detecting cameras. Photos: Wildlife Conservation Society (WCS)*

We ran the FAREAST model at 1,000 randomly selected points within forested areas in the RFE (Fig. 5). At each point, the model was calibrated for temperature, precipitation, elevation and soil characteristics. The model simulates 200 plots or 0.05 ha, starting with bare ground, representing a gap in the forest canopy created when a tree falls. The model was run a second time with a fire probability of 0.006 (6 fires every 1,000 years). The output of the model includes biomass estimates for 44 tree species that occur in the RFE, grouped by genus. We compared the model's total biomass output with and without fire for the 1,000 points and found that further analysis will be needed to distinguish differences in biomass according to parameters such as elevation, age of the forest, slope and aspect.

Fig. 5. B*iomass and LAI were compared at 1,000 random points representing forested areas in Amur tiger habitat in the RFE.*

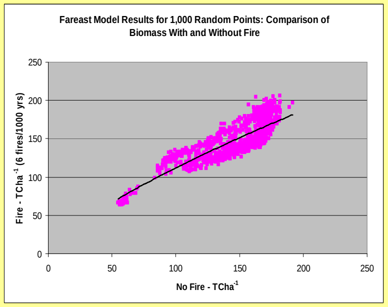

Fig. 6 *FAREAST without fire represents a completely undisturbed forest. Adding fire disturbance creates slight displacement of biomass* ($y = 3.6937x^{0.7409}$, $R^2 = 0.7715$).

The FAREAST model was run at 1,000 points in Primorskiy Krai with no fire risk component and subsequently with a fire occurrence rate of 6 fires in 1,000 years. Model output represents an average of biomass results produced every 10 years between 400 and 500 years of succession. Large areas of Primorskiy Krai contain undisturbed mixed deciduous broadleaf/Korean pine/conifer forests. The original validation of the model indicated that wildfire reduces landscape biomass in successional forests at 300 m elevation and has the opposite effect at 500m, which may be related to site moisture conditions and the maximum biomass levels expected after about 150 – 250 years of succession (Yan and Shugart 2005).

Landcover types in the study area were divided into four forest categories derived from the Moderate Resolution Imaging Spectroradiometer (MODIS) (Friedl et al., 2002) and the Map of Russia's Forests (Bartalev et al., 2004) data: Broadleaf, Dark Coniferous, Mixed, Larch, and Dwarf Siberian Pine. Model outputs for biomass in terms of land cover approximated the remotely- sensed land cover classifications in 336 out of 1,000 locations. The difference in Leaf Area Index (LAI) between FAREAST output and a MODIS-derived estimate (Myneni *et al*., 2002) for the 1,000 points was less than one at 449 points (45%) and less than 0.5 at 186 points (19%).

FAREAST Model

The FAREAST model is an individual-, gap-based model that simulates forest growth in a single location and demonstrates temporally explicit forest succession leading to mature forests. The model incorporates tree characteristics and requirements related to growth, mortality and regeneration, as well as site characteristics, such as elevation, soil moisture and nutrients, and climate parameters, such as temperature and precipitation. FAREAST successfully simulated forest composition in terms of basal area across an elevational gradient at Changbai Mountain and simulated forest composition and successional pattern in terms of biomass at 23 of 31 sites in Russia. It also was able to simulate net primary production (kg C m^{-2} yr^{-1}) versus observed at 593 Forest Survey Stations in China.

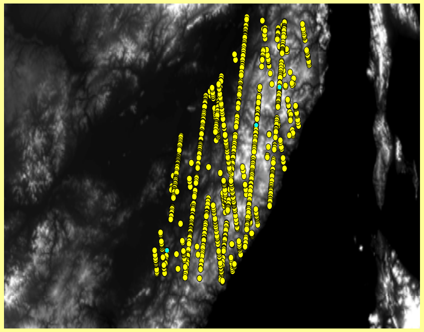

Fig. 7. *Points represent 987 Geoscience Laser Altimeter System (GLAS) data locations for which LAI and biomass estimates ($TCha^{-1}$) derived using two different approaches (described below) were compared.*

We also compared biomass results from FAREAST at 987 points across the entire region with LIDAR-based estimates of biomass (PI – G. Sun). Biomass was derived using allometric equations and then predicted from GLAS waveform indices using neural network. GLAS was designed to measure topography and changes of ice sheets and also provides land topography. The GLAS instrument is carried on the Ice, Cloud and land Elevation Satellite (ICESat), launched in January 2003. By analyzing the sequence of laser data over time, changes in topography can be determined. The initial biomass comparison indicated that further analysis is needed by climate conditions, stage of succession, elevation, slope and aspect.

We also compared FAREAST-produced LAI with LAI estimates derived from MODIS data for the 987 GLAS points and found that the difference in LAI was less than one at 307 (31%) points, less than 0.5 at 123 (12.5%) points, and less than 0.2 at 51 (5%) points.

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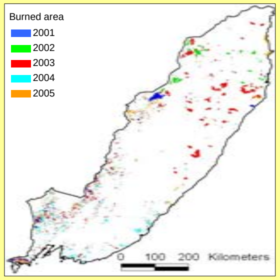
Regionally Specific and Spatially Explicit Estimates of Fire Occurrence

Including spatially explicit information on probabilities of fire occurrence at 1 km resolution developed from the remotely–sensed improves our ability to provide realistic long-term projections of potential forest composition in the RFE. Regionally-adapted burned area product (Loboda *et al*., 2007) and the MODIS active fire product (Giglio *et al*., 2003) were used to map full extent of fire occurrence in the study area during 2001 – 2005.



The occurrence of fire was further analyzed as a function of various landscape components at monthly time-step including:

- land cover
- land use
- topography (aspect, slope, elevation)
- previous disturbance history (previously burned and logged sites)
- proximity to major roads, railroad and towns
- geographic position (latitude and longitude).

Fig 8. *Burned area extent in the RFE during 2001 – 2005.*

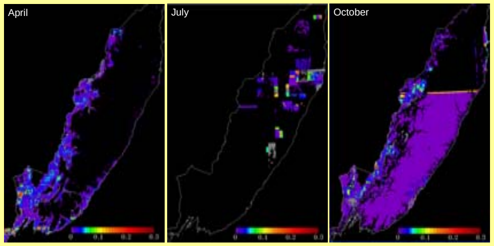


Fig. 9. *Monthly mean fire occurrence probability surfaces were created using the decision tree method based on the analysis of fire data and landscape characteristics.*

Next Steps

The next steps will be 1) to further analyze the results of the FAREAST simulations and calibrate the model with respect to slope and aspect; 2) to modify temperature and precipitation according to climate change scenarios projected in the Intergovernmental Panel on Climate Change 2007 report; 3) to develop a methodology to map disturbance across the study area using remotely sensed data; 4) to analyze discrepancies in biomass between GLAS biomass estimates and FAREAST results in terms of disturbance and likely phase of post-disturbance succession.

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