論文の内容の要旨

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Assessing Impacts of Human Disturbance and Fire on Forests in the Protected Area of Russian Far East using Remote Sensing Data

（リモートセンシングデータを利用したロシア極東の自然保護区の森林における人為攪乱と火災が及ぼす影響評価）

Anthropogenic effects have altered forest globally. Russia is one of the few countries that has remaining large intact forest. The forest in the Russian Far East is now on a long-term decline due to major forest fires and illegal cutting. Because of the low protection and lack of accessibility, the impacts of forest fires and human disturbances in far east region is not well studied, raising concerns in the scientific community about the impact of forest loss and degradation. Major tree die-off and shrinking forest sequestration areas are expected.

The thesis aims to raise awareness within the scientific community to find solution for future challenge of the current impacts on forest loss in the Russian Far East. Many studies pointed out that monitoring the fire influence and possible causes of human disturbances may provide the scientific community with a way to avoid the catastrophic effects of future consequence. The protected area served as important targeted area for my field experiment because the protected area keeps the environment away from human activities and allowing the full potential of ecosystem functioning and the development of forest regrowth after disturbance.

In terms of protected areas, the Russian Federation has its own separate governance structure. The study chose the highest-level restriction area, Zapovednik type as the study area. I selected Zeya Zapovednik, or Zeya State Nature Reserve (hence “The Reserve”) as my study area. The Reserve located in the Zeya city in Amur oblast, the Russian Far East. The Reserve is home to more than 1000 of plant and wildlife species. Many species are red-listed by the International Union for Conservation of Nature (IUCN). Human settlements and recreational activities are strictly prohibited; only staff cabins and instructional activities licensed by the park rangers are permitted. This particular research site is has recently become more vulnerable to anthropogenic threats such as fires and clear-cutting. The Reserve is facing more frequent burning inside the Reserve and illegal clearcutting area around the edge of the Reserve. Extreme impacts from human disturbances degrade forest development and ecological processes, affecting forest cover transitioning over time. Tracking forest disturbance and forest cover transition is therefore essential to protect its natural complexity, biological diversity, and ecological role.

Remote sensing methods are the most advanced way to collect information from large ground area. Using remote sensing data to track and analyze forest changes and disturbances on the environment provides critical information to help scientists address global warming problems. The study used high-quality Landsat images from 1975 to 2019 with less than 10% cloud during the growing season acquired from the United States Geological Survey (USGS) Data Center. The center housed the most extensive continuously collected database of space-based moderate-resolution data, to which scientists and non-scientists from all academic disciplines had free access.

The overall objectives of the study were to analyze forest cover change around protected area in The Russian Far East and evaluate an effectiveness of protected area using remote sensing data. Three critical questions

that lead to new insights for my interested in the Reserve locations included: 1) If the areas did not have frequent image data available, how can we monitor forest cover change and disturbances and effectiveness of protected area by using long-time interval satellite image analysis? 2) How did disturbances distribute around the protected area in relation to environmental and climatic factors? 3) After new images available that allow the research to conduct single image classification, how did forest and disturbance covers change around protected area and can we monitor the stableness of the forest and disturbance covers around protected area based on vegetation indices using short-time interval satellite image analysis? addressing these questions gave me the opportunity to discover how human activities impact interacted to shape the forest ecosystem, particularly in comparison between the protected area and outside protected area.

The outline of the thesis included introduction, study areas, research data, experiment, and discussion. Chapter 1 addressed the study context, general goal, and three specific questions. The background of study area's biodiversity, conservation status, and ecosystem benefits was guided by the study field was described in Chapter 2 with the remote sensing data information. Chapters 3-5 included research questions, approaches, and an interpretation of the results of each experiment to answer the overall objectives and specific questions. From 2016 to 2019, a forest investigation in the field was conducted. There are a total of 23 plots. Six plots were developed in August 2016, eleven in August 2017, and six in August 2018. These data provided information on the physical characteristics of each site, such as habitat type, species composition, disturbance evidence, and vegetation group structure. When doing analysis, these plot-level data are used to check forest cover style position on satellite imagery around protected areas—chapter 3 used six plots from 2016 to address the first question while chapter 5 used all the plots. Chapter 6 presented the general discussion and summarized the conclusions of Chapters 3-5 and addressed the broad questions of whether using remote sensing data can enhance forest cover change detection and whether such research can add value to park information for future management.

For a long term, long-time intervals of two-year-overlaid object-based segmentation classification using nearest neighbors (NNs) classification algorithm were developed using plot surveys and high-resolution photos as references to understand forest dynamics and forest successional stage path. The aim of Chapter 3 was to investigate the effects of disturbance and forest dynamics in the Reserve and surroundings. The chapter used two-year overlaid Landsat images from the Landsat 5 Thematic Mapper (TM) and the Landsat 8 Operational Land Imager (OLI) to produce forest-cover-change maps from 1988 to 1999, 1999 to 2010, and 2010 to 2016. I look at the course of forest successional stages to see how successful the protected area is at preventing fire and human-caused disturbances using vegetation indices. The vegetation indices included the normalized burn ratio (NBR), the normalized difference vegetation index (NDVI), and the normalized difference water index (NDWI). The NDWI was used to distinguish between areas with and without water. The mean NBR and NDVI values were determined to assess the forest successional stages of fire, woodland regeneration, grassland, mixed forest, oak forest, and birch and larch trees. Land dimensions, field photos, and high-resolution photographs were used as sources to determine the accuracy. Overall, the classification results for all three maps are highly accurate more than 80% accuracy. The most disturbed period was from 2010 to 2016. The reserve was well-protected, with no human disturbances. During the period 1999–2010, however, large areas of burned area (137 km2) was discovered inside the Reserve. Burned areas also appeared in the buffer zone and outside of the reserve. Over the period 2010–2016, mixed disturbance rose to nearly 50 km2 in the buffer zone and outside the reserve. Future research

could apply the two-year overlaid image technique in Chapter 3 to compare forest succession and disturbance within and outside the protected area in other ecosystem zones.

The chapter 4 analyzed disturbance types (forest fire, clearcutting for timber and agriculture and mixed disturbance) from Chapter 3 classification results, comparing with environmental factors and climatic factors. The elevation gradient, slope and aspect were obtained from digital elevation model (DEMs) of NASA Shuttle Radar Topographic Mission (SRTM). The study analyzed as patch-wise to calculate largeness and frequency of the disturbance area in different types. The MaxEnt model have been used to produce disturbance vulnerability maps. The climatic data of BIO1-BIO19 bioclimatic factors from Worldclim Version 2.0, averages for the years 1970-2020, were used together with environmental factors, as variable inputs. The results showed most of the disturbance occurrence follow the trend rarely occurred in larger patch size but very frequent in smaller patch size. Most of disturbance in all types have been occurring at the lower elevation, the area closer to the road and at the narrower slope angle, with some exception of forest fire inside of the Reserve that found upon the high elevation and steeper slope angle. Some mixed disturbance was found high in elevation outside of the Reserve and steep slope in the buffer area. Most disturbances occurred in the easily accessible areas. The MaxEnt showed that several climatic factors might potentially influence how the disturbance were distributed around the Reserve, such as, temperature seasonality, annual precipitation, and annual mean temperature. The technique acquired essential information without vast field-based information gathering. The study provided vulnerable area information based on an open-source Landsat data and freely-analyzing software to understand the distribution of disturbances around protected area.

With substantial field investigation and more high-resolution and medium-resolution images, it helps me to use the data until major infrastructure was constructed in the late 1970s. The chapter employed object-based classification using nearest neighbors (NNs) classification algorithm similar to Chapter 3 to classify eleven single-year images (1975, 1988, 1993, 1996, 1999, 2001, 2005, 2010, 2014, 2016, 2019) and eleven time-series forest cover maps were generated. Then, I roughly estimated area changes of forest covers and disturbances. I proposed a change vector analysis (CVA) method to evaluate the change of stableness of forest cover and disturbance classes in the inside, buffer, and outside zones of the Reserve by using spectral characteristics based on vegetation indices: the NDVI and NBR. Because there was neither a SWIR band nor an additional NIR band in the Landsat 2 MSS, the study excluded 1975 for the NDVI and NBR vegetation index analysis. The vegetation index was calculated pixel-wise. The average index value of pixels representing each class were compare between years. Mixed disturbance and forest fire showed a significant increasing trend while grassland showed the opposite trend. The disturbance classes showed large change magnitude of change (S) or stableness between pre-and post- period compared with the forest classes. The classes inside the Reserve contain smaller change of stableness between pre- and post- period, indicating that the inside of the Reserve is effective in term of preventing human disturbance and maintaining the forest area from the past to present.

The thesis results showed that the overall objective and specific questions were mostly accomplished using remote sensing data. Such tools are very essential to detect forest fire and forest cover changes around the Reserve's protected area. The large and remote spatial extents only allowed remote sensing as feasible method to observed forest dynamics from a far. By applying object-based segmentation classification method using long-time interval classification technique or single year technique could provide details of forest cover change and disturbance in more meaningful way.

Even though the Reserve is very well protected, there is no guarantee that the forest cover and disturbance patterns around the reserve will not affect forest dynamics inside the reserve. If there are more frequent massive burning, the reserve will face difficulty in maintaining its biological diversity and ecological function. There is an urgent need of multi spatial-scale study of how forest fire behaved in recent time. The frequency, intensity, and severity data will enrich more knowledge of susceptible area. Unexpected climate events could cause severe damage to boreal forest, thus more understanding about the impacts of forest fires and human disturbance is needed to establish better management for preserving biological diversity and ecological resources. The study provides supporting evidence of forest fires in remote protected area. I recommend that future studies to apply knowledge from the thesis to other protected areas, so that we can understand the effectiveness of forest conservation there as well.