EVALUATION OF LAND-COVER CHANGE IN AMUR BASIN USING NDVI DERIVED FROM NOAA/AVHRR PAL DATASET

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ABSTRACT

The authors analyzed recent land-cover change in the Amur River basin using a technique proposed by Kondoh (2004) for the analysis of satellite data (NOAA/AVHRR PAL dataset). The aim was to obtain an objective evaluation of how agricultural activity is affecting the natural environment of this area. Four parameters, ΣNDVI, NDVImax, NDVIstd, and TRJ were adopted to reflect surface conditions, and their linear trends from 1982 to 2000 were examined. Signs of land-cover change were apparent in the five areas chosen for further study. In particular, in Heilongjiang Province land-cover change through agricultural activity was detectable by this analysis.

Key word: The Amur River Basin, NDVI,NOAA,Land cover change

1. BACKGROUND OF STUDY

The Amur River is an international river with a total length of 4350 km and a huge drainage area of 2,051,500 km^2. Its upstream region is in Mongolia, which has a steppe climate (Köppen's Bs world climate zone). Its midstream and downstream regions flow through China and the vicinity of the Russian border, which lies in the cool-temperate zone with low winter rainfall (Dw zone).

Recently, environmental changes originating in the land-cover change have been occurring in the Amur River basin. For instance, the wetland habitat of the crane has been shrinking because of land development, increased sedimentation of rivers through the development of arable land, increased chemical loading of rivers through the expansion of agricultural activity, and air pollution due to forest fires.

In particular, the agriculture has been developed by Chinese government and the cultivated area has been increased in these 20 years in Heilongjiang Province[1]), and the area has changed into an important food production region[2]).

In contrast, the Russian territory through which the river passes has been in a state of economic depression since the collapse of the old Soviet federation. Therefore, the regional differences in land-cover change in the Amur River basin are great. An objective evaluation of the factors influencing anthropogenic land-cover change in the basin is needed [3]). The only research data that we have on land-use and land-cover change in the area is the results of statistical material analyses of individual regions[4]). There has been no research on the entire Amur River basin; nor has there been any research on secular variations in land cover.

We therefore performed satellite remote-sensing research on the secular variations in land cover over the entire Amur River basin. By using the NDVI (Normalized Difference Vegetation Index), we aimed to pinpoint regions that are experiencing marked land-cover changes and to explain the trends in these changes.

2. OUTLINE OF STUDY AREA

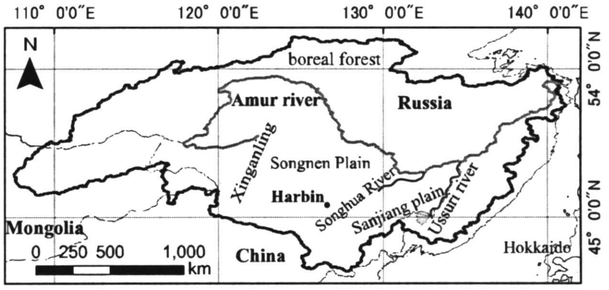

Figure 1. Amur River basin

The Amur River basin is located at lat 41.42°–55.56°N and long 107.32°–141.70°E. The direction of the flow of the Amur River changes as the river courses from midstream to downstream to the east. The river is joined by the Ussuri River which flows from south to north around Khabarovsk, and by the Songhua River which flows from southwest to northeast around Sanjiang Plain (Figure 1). Structural geographical changes are seen in the Amur River basin as the river flows from west to east. The mountainous district more than 1000 m above sea level (asl) extends to the west, and plains where the altitude is below 100 m spread out around Sanjiang plain (Figure 2).

Peat wetlands are distributed in the floodplains and on the plains of the valley bottoms in the hilly country south of the Amur River. Agricultural activity is active in the eastern Amur River basin. However, the climate is very cold: in the city of Harbin the annual mean temperature is 4.6 °C, and the temperature in January is –20 °C [5]). The monthly mean temperature in July is 25 °C, and rainfall is concentrated in summer. Only one crop is planted each year in the Amur River basin[6]).

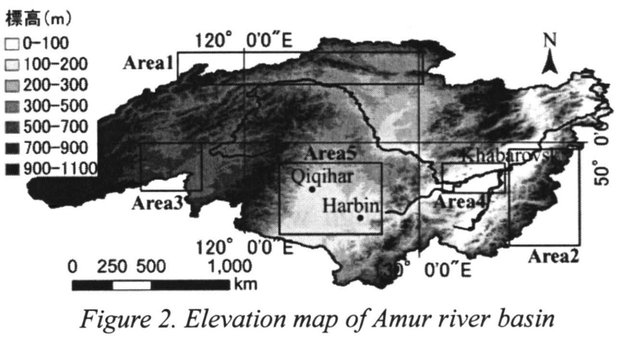

Figure 2. Elevation map of Amur river basin

3. DATA USED

3.1. NOAA/AVHRR PAL Dataset (PAL data)

Pathfinder AVHRR(Advanced Very High Resolution Radiometer) Land (PAL) data offered by the DAAC (Data Active Archive Center) of NASA/GSFC (National Aeronautics and Space Administration / Goddard Space Flight Center) was used to analyze land-cover changes in the Amur basin. The PAL dataset was collected by the AVHRR sensor installed on the NOAA (National Oceanic and Atmospheric Administration) weather satellite; Ch (channel). 1 (visible light), Ch. 2 (near-infrared rays), Ch. 4, Ch. 5 (heat infrared rays), and NDVI data are included. PAL data from July 1981 are available and can be analyzed from 1982 to 2000 to use the whole year data. Moreover, because PAL data are collected globally, the entire Amur River basin could be analyzed: this is why this dataset was the most suitable for the study.

The PAL data are composites collected every 10 days, and include data divided the year into 36 seasons. The spatial resolution is converted from 8km into 0.1° (about 10 km) of both latitude and longitude with the tool that the homepage offered (http://daac.gsfc.nasa.gov).

The NDVI relates to the density and active growth of green plants, and it can be calculated from differences in the spectral reflection of chlorophyll in the visible light and near-infrared ranges[7]). NDVI is widely used for the observation and evaluation of vegetation, and it is assumed to be related to vegetation parameters such as land cover[8]), leaf area index (LAI) [9]), and biomass[10]). In PAL data, NDVI is calculated by the following formula.

$$NDVI = (Ch.\ 2 - Ch.\ 1) / (Ch.\ 2 + Ch.\ 1)$$

3.2. Statistical materials used in the agricultural and field investigation

The amount of land in Heilongjiang Province transformed for irrigation between 1980 and 2000 was determined from the Heilongjiang Province statistical yearbook (2001). Moreover, the area sown to the main commercial crops between 1978 and 2000 and the patterns of transition of production were determined from the statistical material[11]). In September 2005 we performed a field investigation in which we used GPS and digital cameras to observe and record the land cover in the Sanjiang plain, the Songnen Plain and around Khabarovsk Krai.

4. METHOD OF STUDY: ANALYSIS OF SECULAR VARIATION FROM 1982 TO 2000

We used the technique proposed in 2004 by Kondoh to analyze the global-scale vegetation and land-cover changes from 1982 to 2000 from the PAL data [12]) and to thus clarify the land-cover changes over the entire Amur River basin. Coordinates were given to the image by geometric collection. The following four parameters were used for the analysis: sum of NDVI (ΣNDVI) during the year; maximum NDVI ($NDVI_{max}$), standard deviation ($NDVI_{std}$) of ΣNDVI; and the trajectory on the Ts (surface temperature)–NDVI scatter chart (TRJ) [13]). The flow chart in Figure 3 was used for PAL data analysis.

$NDVI_{max}$ is used as an index related to the production of commercial crops, because it shows the growth situation of plants in every year. ΣNDVI is an index that corresponds to the biomass each year. $NDVI_{std}$ is used as an index that shows the disturbance of vegetation, because it shows the level of biomass increase and decrease every year. For instance, both ΣNDVI and $NDVI_{std}$ change throughout the year in regions where floods and forest fire occur frequently and in regions where a big difference in the growth of vegetation by the timing of snow melting in each year.

The TRJ is an index that shows the direction of the land cover change (For instance, the value of TRJ shows positive when there is a tendency to the land cover change from the forest to the bare ground). TRJ is obtained from the scatter chart of Ts and NDVI. NDVI is shown on the horizontal axis and Ts on the vertical axis. Land-cover change can be calculated by applying a straight line to the tracks for every year, and analyzing the change in inclination of the straight line over 19 years. The inclination of the TRJ grows when the land cover changes from meadow to bare ground and the inclination of the TRJ declines when the land cover changes into forest.

As a threshold between vegetated and non-vegetated, the commonly used value of NDVI = 0.1 was applied[12]). Pixels whose NDVI is lower than 0.1 are judged as non-vegetated regions and excluded from the calculation. Moreover, the validity of the PAL data analysis results was verified by above-mentioned statistical material analysis and the regional field investigation; thus the areas in which the influence of artificial land alteration was greatest were determined.

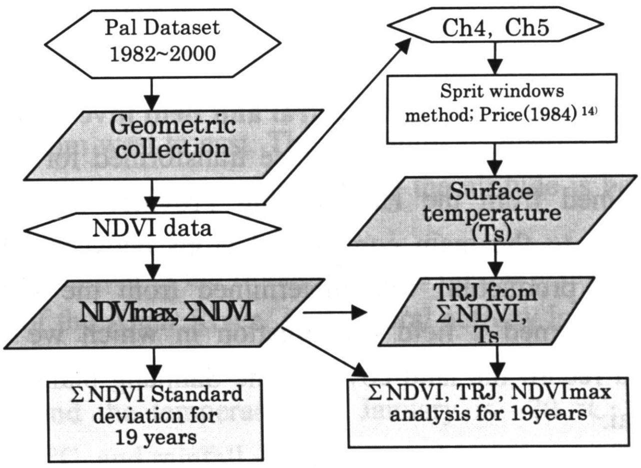

Figure 3 Flow chart of PAL data analysis

5. RESULTS AND CONSIDERATION

5.1. Analysis of secular variation in land cover from 1982 to 2000

The NDVI value falls below the threshold in winter because the Amur River basin is covered with snow. Therefore, the secular variation in each parameter represents the NDVI changes from early spring to autumn. Figures 4 to 7 show the changes in each NDVI index in the Amur River basin over the 19-year period (1982–2000). From among these results we selected and interpreted five regions in which the changes in each parameter were clear.

5.1.1. Area 1

Area 1 is located between lat 52.75°–54.85°N and long 116.75°–130.35°E and is covered by extensive coniferous forest. Figure 5 shows that the value of ΣNDVI increased over this area. The area of ΣNDVI = 0.05 or more extended both east and west and was distributed in a low mountainous district 500 to 800 m asl. $NDVI_{std}$ was also high (1.5 or more) (Figure 6) in the area where ΣNDVI is high. No remarkable change in $NDVI_{max}$ (Figure 4) or TRJ (Figure 7) was seen across the region.

In 1997 Myneni found increased vegetation activity and discussed the relationship of this activity to global warming in northern Eurasia, Alaska, and the Canadian northwest (lat 45°00–70°00N) during the period 1982–1990 [7]). Moreover, the temperature rose by 4 °C in winter in these three regions during 1961–1990 [15]). Therefore, this temperature change appears to have been reflected in an increase in ΣNDVI in that the vegetation growth period was extended: the snow melted in early spring because the temperature rose early in winter. Moreover, the value of $NDVI_{std}$ increased because the difference in ΣNDVI within each year was large; Area 1 can thus be interpreted as a region influenced readily by both yearly changes in meteorological conditions and global climate change.

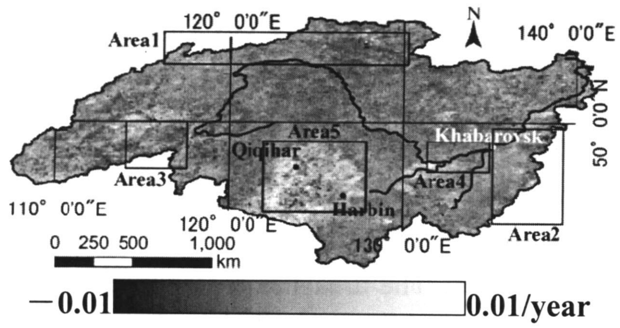

Figure 4. **$NDVI_{max}$** *(secular variation 1982–2000)*

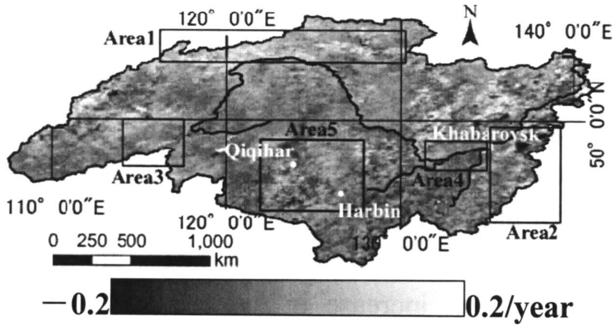

Figure 5. **ΣNDVI** *(secular variation 1982–2000)*

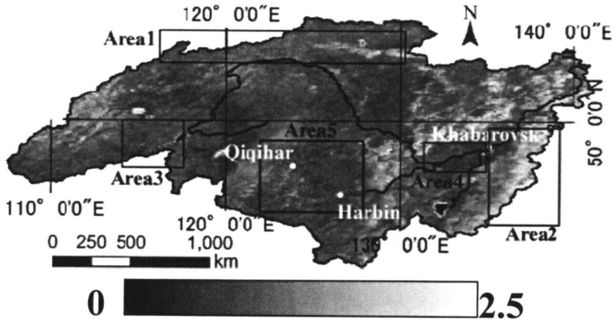

Figure 6. **$NDVI_{std}$** *(secular variation 1982–2000)*

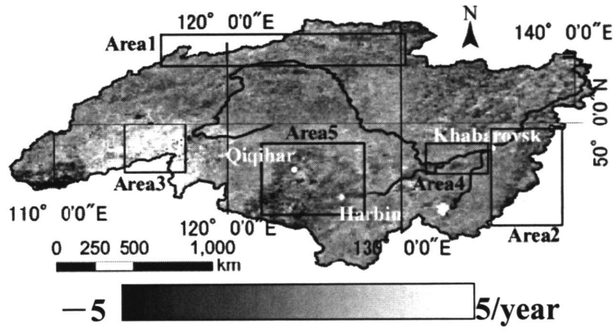

Figure 7. **TRJ** *(secular variation 1982–2000)*

5.1.2. Area 2

Area 2 is located at lat 43.65°–50.15°N and long 134.65°–140.75°E. In this region coniferous forests extend from 500–1300 m asl. An area where $NDVI_{std}$ was greater than 1.5 (Figure 6) and ΣNDVI was 0.05 (Figure 5) was distributed from southwest to northeast along the basin's boundary. No marked change was seen in $NDVI_{max}$ or TRJ (Figures 4, 7). However, an area of ΣNDVI = –0.21 (decreased biomass) extended from Khabarovsk to about 250 km eastward. Large-scale forest fires occurred in Khabarovsk Territory in 1976, 1998–1999, and 2001, and the Far Eastern taiga covering 25,000 km^2 received damage in 1998 [16]). We consider that this decrease in ΣNDVI in Area 2, and thus the decrease in biomass, resulted from the frequent forest fires.

5.1.3. Area 3

Area 3 is located at lat 47.00°–50.00°N, long 114.50°–118.00°. In this region the plateaus and hills extend to 550–900 m asl. The area has a steppe climate, and the main region is covered by meadow vegetation. The whole area had TRJ = 3 (Figure 7), but ΣNDVI, $NDVI_{max}$, and $NDVI_{std}$ (Figures 4, 5, 6) showed no marked changes.

Therefore, the increase in TRJ must be derived from an increase in Ts. Generally, with meadow vegetation such as that in Area 3, there is a period of bare ground between snow melting and foliation. Consideration of ΣNDVI, $NDVI_{max}$, $NDVI_{std}$, and the vegetation of Area 3 leads to the interpretation that the period of bare ground increased over the 19 years, and the Ts rose because snow melt occurred increasingly early; as a result, the TRJ increased.

Moreover, when supplementing for the NDVI index, an increase in the bare ground period is not simply related to an increase in the biomass in the meadow vegetation of Mongolia. Because it receives a complex influence according to the temperature, precipitation and soil water content[17]). Kondoh et al. (2002) divided the vegetation zone in the world into the vegetation zone of the water dependence and the energy dependence[18]), Area 3 is located in the transition belt of both. When the influence of the climate change and the man activity expected in the 21st century is foreseen, the boundary of the ecology zone is thought to be the weakest region. Therefore, it is scheduled that it keeps monitoring in the future and a detailed research is done about an increase of TRJ in this area.

5.1.4. Area 4

Area 4 is located at lat 46.55°–47.85°N, long 129.55°–134.05°E. This region is known as the Sanjiang Plain, and here the floodplain is distributed to about 50–70 m asl. North and south part of the Songhua River, the $NDVI_{max}$ = 0.008 (Figure 4) and the TRJ was about –3.0 (Figure 7). In particular, the changes in these parameters on the floodplain between the Songhua River and the Amur River are plain. When biomass increases and the conditions for vegetation growth improve, transpiration becomes active and Ts decreases. Moreover, the heat budget at ground level is changed by water transmission via irrigation and Ts decreases [12]). TRJ decreased by these factors. Therefore, the secular variation in each parameter in Area 4 can be interpreted as showing land-cover change through the development of agricultural activity.

From viewpoint of biological diversity, the wetlands in this plain are important natural environment. Further research is requested about what influence the reclamation of the wetland gives natural environment especially, in this area.

5.1.5. Area 5

Area 5 is located at lat 44.75°–48.75°N and long 121.85°–128.05°E and is called the Songnen Plain. An increase in $NDVI_{max}$ (Figure 4) was clear on the floodplain and on the hills, which are at an altitude of about 130–280 m. The $NDVI_{max}$ was 0.005 in the hill zone to the north of the city of Harbin. The hill zone to the west or southwest of the city of Quiqihar had a larger $NDVI_{max}$ (0.006). ΣNDVI and TRJ (Figures 5, 7) also showed obvious changes in the floodplain and hill zones: TRJ was below –1 and ΣNDVI equaled 0.1.

In Area 5, an area that extends for 200 km north of the city of Harbin and has seen a marked expansion in the area under rice cultivation since the 1980s [4], the ΣNDVI was 0.08 and the $NDVI_{max}$ was 0.005 (Figures 4, 5). The trends in each parameter were similar to those in Area 4 and can be interpreted as indicative of land-cover change in response to the development of agricultural activity. ΣNDVI increased in the low mountainous districts (especially those higher than 200 m asl), suggesting that increases in afforestation, as well as in agricultural activity, increased the ΣNDVI[4]).

5.2. Verification of validity of PAL data analysis

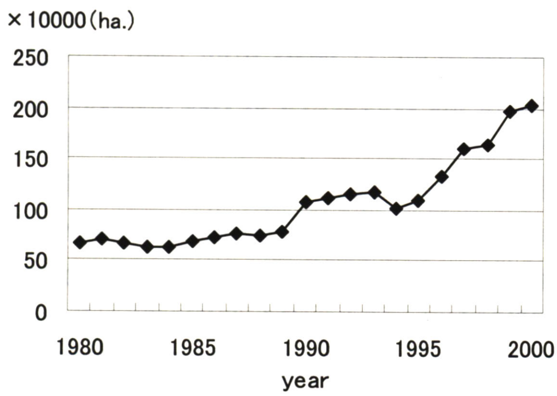

Figure 8. Transition of area under irrigation in Heilongjiang Province

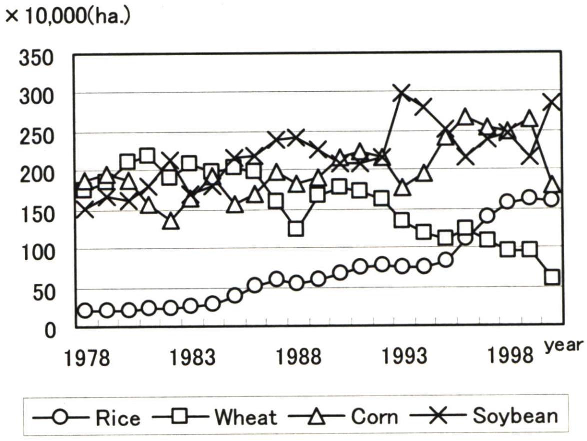

Figure 9. Transition of area sown to commercial crops in Heilongjiang Province

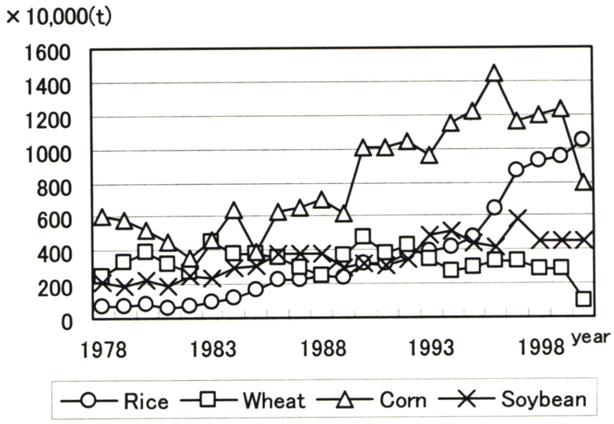

Figure 10. Transition in production of commercial crops in Heilongjiang Province

The validity of PAL data analysis was verified by analyzing agricultural statistics from Heilongjiang Province. Statistics for Areas 4 and 5 were used, because we considered that the influence of artificial land alteration was the greatest in these two areas out of the whole Amur River basin. These regions are important food production regions of Heilongjiang Province.

The area of Heilongjiang Province under irrigation expanded rapidly by 300% or more (from 670,500 to 2,032,000 ha) in the 21 years from 1980 through 2000 (Figure 8). The area sown to commercial crops and the production of rice increased greatly in the 23 years from 1978 through 2000 (750%—214,100 to 1,606,000 ha—in the case of planted area and 1460%—715,000 to 10,422,000 t—in the case of rice harvest (Figures 9, 10).

Moreover, the increase of corn production is remarkable in the first half of the 90's. And in the rice farming, both area and production increase as a rapid increase of the irrigation area since the latter half of the 90's.

In our September 2005 field investigation, we confirmed that floodplains were being used for rice fields, hillside terraces for soybean fields, and hills for cornfields. Only parts of the wetlands remained. Therefore, in Area4 and 5, the irrigation maintenance is done to the upland farming (Wheat, corn and soybean) at the beginning of the 1990's, and the irrigation area has increased. As a result, it is thought that production increased around corn fields. On the other hand, an increase in the irrigation area in the latter half of the 1990's is thought to be rice field development by the wetland reclamation because of the increase of rice production and sown area in this period.

The land cover change by the development of an agricultural activity was shown by analyzing PAL dataset in these regions. It is thought that this analysis caught the change in an agricultural form like the above-mentioned.

6. SUMMARY

We demonstrated the trends in land-cover change in the Amur Basin from 1982 to 2000 spatially by using four indices calculated from the NDVI. Moreover, we were able to explain the land-cover change in five selected areas by combining and interpreting these indices. Land-cover change in the Amur River basin is especially remarkable in the grain production region of Heilongjiang Province in China.

To validate the results of the PAL data analysis, we performed a statistical material analysis and field investigation for Areas 4 (Sanjiang Plain) and 5 (Songnen Plain). We confirmed that the secular variation in each parameter in these regions was associated with arable land development for irrigation and with land-cover changes from rice farming development.

Thus, the transformation of the region from past to present was clarified by this land-cover change study. This research should be helpful in planning the future development and administration of the basin. By using data on land-cover change and elevation it should also be possible to approximate the changes in volumes of materials transported into the river.

ACKNOWLEDGMENT

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