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SPATIAL ASSESSMENT OF THE ALDER TREE IN KUSHIRO MIRE, JAPAN USING REMOTELY SENSED IMAGERY – EFFECTS OF THE SURROUNDING LAND USE ON KUSHIRO MIRE

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Abstract. The relationship between alder (*Alnus japonica*) distribution and surrounding land use in Kushiro Mire was spatially assessed using remotely sensed imagery. From the result, it was found out that the expanding area of alder trees in Kushiro Mire was affected by the agricultural land area in the upper course of the river basin and flooding in the lower course of the river. The soil sediments flowing into the Kushiro Mire from the agricultural land resulted in heavy sedimentation that favors the growth of alder trees. Consequently, the number and density of alder trees has increased. The future distribution of alder trees was predicted based on the mechanism of expansion of the alder-tree area in Kushiro Mire, and it was found that large vegetation areas in Kushiro Mire will be changed to areas with alder trees.

Keywords: agricultural land, flooding, Landsat, remote sensing, soil sediments, spatial assessment

1. Introduction

Wetlands are estimated to cover about 4–6% of the world's land area (Mitsch and Gosselink, 1993), and covers more than 20% of the landscape in boreal regions where great expanses of peat lands are found (Gorham, 1991). One of the most important roles of wetlands is its function as linchpins of global climate change that sequesters and releases major portion of fixed carbon in the biosphere (Mitsch and Wu, 1995). Costanza *et al.* (1997) estimated that wetlands are 75% more valuable than lakes and rivers, 15 times more valuable than forests, and 64 times more valuable than grasslands and rangelands. Wetlands also serve as an important relay ground or habitat for migratory birds. They are an important site of wildlife conservation and wildfowl, and genetic pools of various and precious flora and fauna (Adams and Hollis, 1988; Adams, 1993; Hollis *et al.*, 1993; Mitsch and Gosselink, 1993; Thomas *et al.*, 1993). Moreover, it is also important for the generation of carbon dioxide and methane gases, which cause global warming. Natural wetlands are major source of methane (CH_4), emitting approximately 21% of the total global emissions to the atmosphere (Intergovernmental Panel on Climate Change (IPCC, 1995)).

Wetlands are often heterogeneously distributed in many landscapes, particularly in glaciated regions. These wetlands generally appear as small isolated patches that are strongly influenced by their surrounding matrix. The patchy nature of wetlands resemble 'biogeographical islands' at a local scale, but a shift in scale may reveal that individual wetland patched may cluster to form a large wetland complex (Whited *et al.*, 2000). Wetland assessment techniques have generally focused on rapid evaluation. But a method in which the land cover distribution of this large wetland complex is measured precisely to assess environmental change is necessary because large wetland complexes are a delicate environment that are easily affected by human development.

The Kushiro Mire, with 18,000 ha, is the largest wetland area in Japan. The importance of preserving the biodiversity of the Kushiro Mire wetlands was discussed at the Ramsar Convention (Iwakuma, 1996). Most of the Kushiro Mire consists of fen covered with reeds and sedge grasses, while some parts of the wetland are bog areas covered with sphagnum moss. The northern part of the wetland is covered with alder (*Alnus japonica*) (Oguma and Yamagata, 1997). The number, canopy area, and density of alder trees in the Kushiro Mire have increased dramatically over the last 50 years. Alders are sensitive to small changes in the environment. They grow best in areas where soil accumulates due to sedimentation and water level has stabilized. It has been reported that alders can be used as an index of aridity and eutrophication in wetlands (Yamagata, 1999).

In recent years, nutrient-rich water and soil sediment have been flowing into the Kushiro Mire from the north due to rapid development in the surrounding land. As a result, the vegetation distribution pattern in the wetland has undergone a rapid change (Nakamura *et al.*, 1997; Nagasaka and Nakamura, 1999). In particular, the wetland vegetation has been changed due to the dramatic increase in the number and density of alder trees, which express aridity. However, previous studies have not considered the full distribution of alders over the entire mire. Hence, it is necessary that the relationship between alder tree distribution and environmental changes around Kushiro Mire be spatially assessed to better understand and explain the dramatic increase in the number and density of alder trees. As it will be difficult and costly to evaluate the alder distribution and the surrounding land use in Kushiro Mire, by field survey, remotely sensed imagery was considered to be potentially useful for the task (Yasuoka *et al.*, 1994).

Several case studies have used remotely sensed data to classify vegetation in Kushiro Mire (Yasuoka *et al.*, 1994; Oguma and Yamagata, 1997; Yamagata, 1999). These papers utilized a vegetation classification map of Kushiro Mire produced by the National Institute for Environmental Studies of Japan based on Landsat Thematic Mapper data. There has also been a case study in which the precise area of alders in Kushiro Mire was determined from TM imagery (Oki *et al.*, 2002). However, there have been no spatial evaluation of the relationship between alder distribution and surrounding land use in Kushiro Mire using remotely sensed imagery. Therefore, this study used remotely sensed imagery to evaluate the relationship between alder distribution and surrounding land use in Kushiro Mire. The objective is to explain the mechanism of alder-area expansion in Kushiro Mire, and consequently predict the future distribution of alder trees.

2. Data and Methods

2.1. CHARACTERISTICS OF THE KUSHIRO MIRE

The Kushiro Mire, which is about 18,000 ha, is the largest wetland area in Japan. It is located in the eastern part of the Hokkaido region (Figure 1). The wetland was formed by accumulation of peat over the last 400 years with depth ranging from 1 to 4 m. The average temperature in the area is about 5.5 °C, and the annual precipitation averages to 1100 mm. The wetland is recognized as one of the most important ecosystems in terms of species diversity, and its conservation was proposed at the Ramsar Convention (Iwakuma, 1996; Yamagata, 1999).

Most of the Kushiro Mire area consists of fen covered with reeds and sedge grasses, while some parts of the wetland are bog areas covered with sphagnum moss.

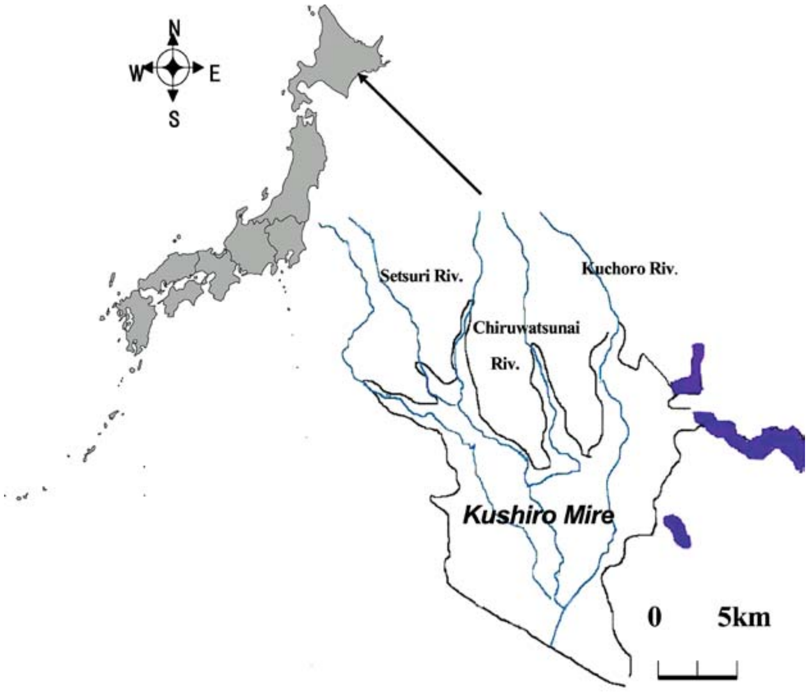


Figure 1. Location of the Kushiro Mire in Hokkaido.

The northern part of the wetland is covered with alder (*Alnus japonica*) (Oguma and Yamagata, 1997). Fen is defined here as peat-producing wetland influenced by soil nutrients from water flowing through the system. A bog area is a peat-producing wetland in moist climate, where organic material has accumulated over long periods. Water and nutrient goes into the system through precipitation and runoff. In recent years, nutrient-rich water and soil sediment have been flowing into the Kushiro mire from the north due to rapid development in the surrounding agricultural areas. As a result, the vegetation distribution pattern in the wetland has undergone a rapid change (Nakamura *et al.*, 1997; Nagasaka and Nakamura, 1999). In particular, the number and density of alder trees have increased dramatically during the last 50 years. Because alder trees can grow well in areas where there's accumulation of soil due to sedimentation, this resulted in rapid changes in vegetation in wetlands. Therefore, it is necessary that the relationship between alder tree distribution and environmental changes around Kushiro Mire be spatially assessed.

2.2. SATELLITE DATA

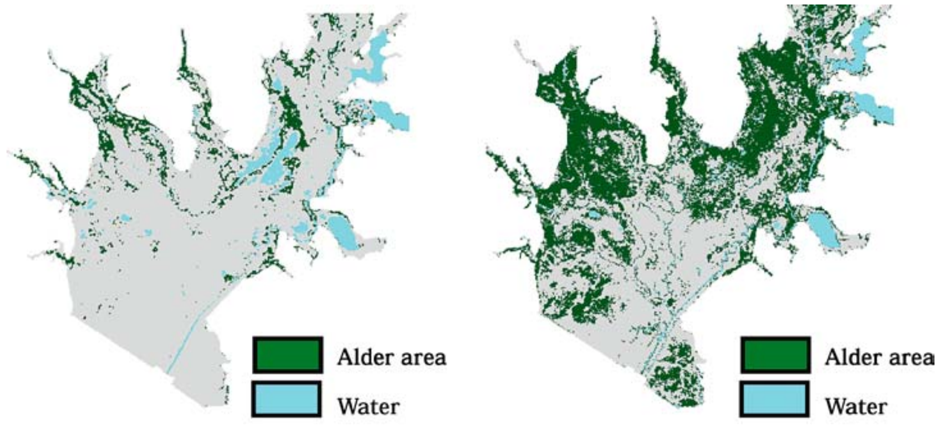
We used Landsat Multispectral Scanner (MSS) and Thematic Mapper (TM) data to evaluate the spatial relationship between alder tree distribution and environmental changes around Kushiro Mire. The MSS is an optical sensor mounted on Landsat 1 to Landsat 5. Landsat 1 with the MSS was launched in 1972 as a first sensor. The MSS has four bands, which are 0.5–0.6 μm (band 4), 0.6–0.7 μm (band 5), 0.7–0.8 μm (band 6), and 0.8–1.1 μm (band 7) in the visible to the near-infrared region. The spatial resolution is approximately 80 m. On the other hand, the TM is an optical sensor mounted on Landsat 4 and Landsat 5. The TM has seven bands, namely 0.45–0.52 μm (band 1), 0.52–0.60 μm (band 2), 0.63–0.69 μm (band 3), 0.76–0.90 μm (band 4), 1.55–1.75 μm (band 5), 10.40–12.50 μm (band 6), and 2.08–2.35 μm (band 7). The spatial resolution of these bands except for band 6 is 30 m. Band 6 has 120 m spatial resolution. In comparison with the MSS, the TM has higher number of spectral bands and spatial resolution.

2.3. ALDER TREE MAPS

In this study, we produced alder tree maps in order to evaluate the change of spatial patterns of alder tree areas in Kushiro Mire. The maps were classified into three categories (alder, water, and other) by the ISODATA method using Landsat MSS (7 June 1979) and TM data (25 August 1981, 27 July 1985, 7 June 1990, 1 July 1993, 26 August 1996, 15 July 1998, and 22 September 2000) based on vegetation maps made by field survey. The ISODATA method is an unsupervised classification, which identify statistical patterns in the data without any ground truth data. The clustering method uses the minimum spectral distance formula to form clusters (ERDAS, 1997). Also, Landsat TM is better than MSS data for evaluating the Kushiro Mire, because its spatial resolution is 30 m, *versus* 80 m for MSS data.

The use of Landsat TM began in the 1980s, whereas MSS imagery was used to evaluate the wetlands in the 1970s. TM imagery does not use the thermal infrared band (band 6) in the classification. In this study, each Landsat MSS/TM image was corrected geometrically using the TM imagery of 25 August 1981. A nearest-neighbor interpolation method was used to prevent the original pixel values from being annulled. As a result, the error of superposed Landsat MSS/TM imagery was less than 1.0 pixel.

Figure 2 shows sample alder tree maps made from Landsat imagery in Kushiro Mire taken 7 June 1979 and 26 August 1996, and Figure 3 shows the change of alder-tree area calculated from alder tree maps in Kushiro Mire from 1979 to 2000. From Figures 2 and 3, it can be seen that the alder-tree area has increased dramatically, particularly in the Kuchoro and Setsuri River basins.



(a) 1979 (b) 1996

Figure 2. Alder trees maps made from landsat imagery observed on (a) 7 June 1979 and (b) 26 August 1996.

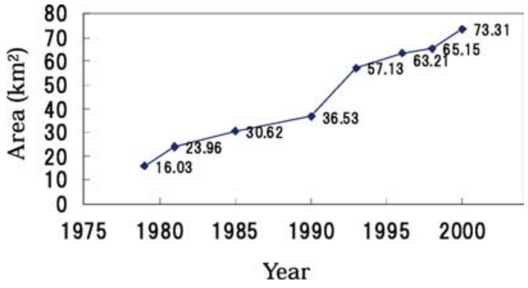


Figure 3. The change of alder-tree area calculated from alder tree maps in Kushiro Mire from 1979 to 2000.

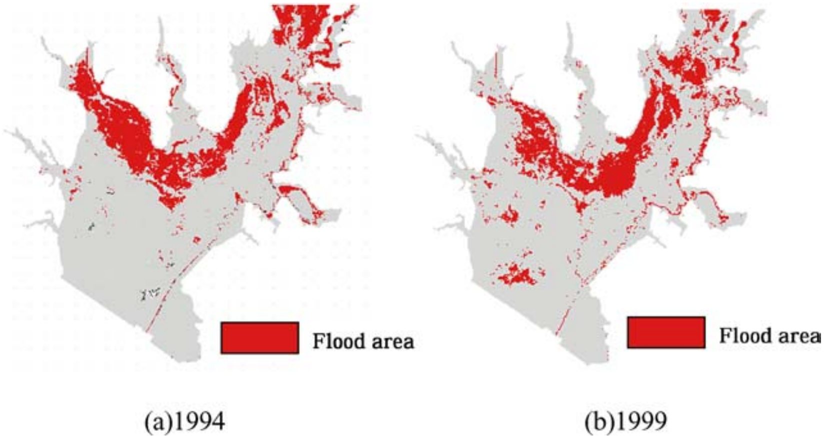
3. Results and Discussion

3.1. RELATIONSHIP BETWEEN ALDER TREE DISTRIBUTION AND FLOODED AREA

It has been reported that the increase of the alder-tree area is closely related to flooding in Kushiro Mire. This is because alder trees grow well in sites with soil accumulation caused by sedimentation (Nakamura *et al*., 1997; Yamagata, 1999). In this section, the relationship between alder tree distribution and flood area was evaluated spatially using remotely sensed imagery.

In general, flooding of Kushiro Mire occurs in the snowmelt season in May and the typhoon season in September. However, it is difficult to monitor the Kushiro Mire using remotely sensed imagery in September because of heavy cloud coverage. Therefore, Landsat imagery from May 1994 and 1999 was used to determine the flood area. Figures 4(a) and 4(b) show the flood area of Kushiro Mire determined from maps, which are classified into three categories (alder, water, and other) by the ISODATA method using Landsat TM data from 17 May 1994 and 31 May 1999.

Figures 4(a) and 4(b) show the flooding in the lower course of the Kuchoro and Setsuri Rivers. Flooding was very slight in the Chiruwatsunai River basin. From Figures 2 and 4(a) and 4(b), it can be seen that there is a relationship between alder tree distribution and flood area in Kushiro Mire. The increase in flooded area results in increase in density of alder tree after flooding. Therefore, using remotely sensed imagery, it was confirmed spatially that the increase of the alder tree area is closely related to the flood in Kushiro Mire.



(a)1994 (b)1999

Figure 4. The flood area of Kushiro Mire determined from maps classified into three categories (alder, water, and others) by the ISODATA method with Landsat TM data from (a) 17 May 1994 and (b) 31 May 1999.

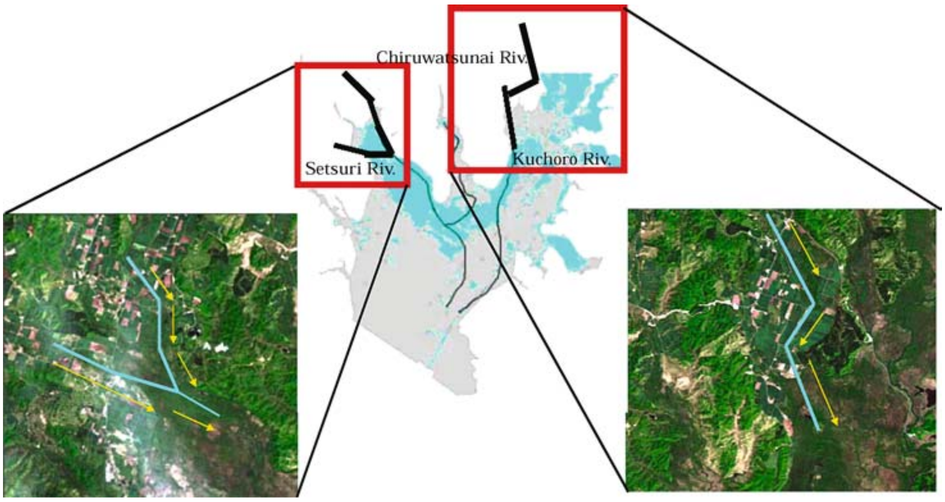


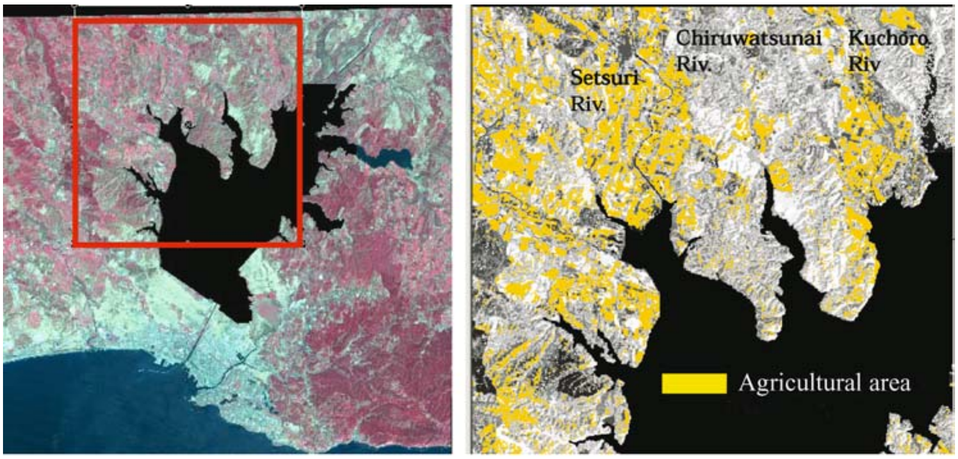
Figure 5. Enlargements of the imagery of the Kuchoro and Setsuri River basins.

Figure 5 shows the enlargements of the imagery of the Kuchoro and Setsuri River basins. From Figure 5, it can be seen that the shape of the Kuchoro and Setsuri Rivers was straight in contrast to the shape of the Chiruwatsunai River (flooding was slight). Construction work to enhance the linearity of the Kuchoro and Setsuri Rivers began in 1960s. This construction project was designed to improve the drainage of agricultural land located in the upper course of the Kuchoro and Setsuri Rivers. However, the force of water has strengthened the flow, as the rivers grew steeper as a result of the construction work. Thus flooding became more likely in the lower course of the rivers. This would seem to be the cause of the flooding in the lower course of the Kuchoro and Setsuri Rivers. From the remotely sensed imagery shown in Figures 4 and 5, it was also confirmed that the flood was generated in the lower course of the Kuchoro and Setsuri Rivers.

3.2. RELATIONSHIP BETWEEN ALDER TREE DISTRIBUTION AND LAND USE

In this section, we analyze the land-use conditions around Kushiro Mire using remotely sensed imagery in order to spatially assess the source of sedimentation and accumulation of soil in Kushiro Mire. Figure 6(a) is the Landsat TM data on 17 May 1994 showing the Kushiro Mire (black) and the area surrounding area. Figure 6(b) shows the agricultural land in the upper course of the Kuchoro, Chiruwatsunai, and Setsuri Rivers enlarged from Figure 6(a). The agricultural land in Figure 6(b) (yellow) was extracted from a map classified by the ISODATA method. The main area of the extracted agricultural land consisted of meadows.

From the remotely sensed imagery in Figure 6(b), it was confirmed that there was little agricultural area in the upper course of the Chiruwatsunai River, but there



(a) (b)

Figure 6. Kushiro Mire and the area around Kushiro Mire observed by Landsat TM data on 17 May 1994. Part (b) shows agricultural land in the upper course of the Kuchoro, Chiruwatsunai, and Setsuri Rivers enlarged from (a).

was abundant agricultural area in the upper course of the Kuchoro and Setsuri Rivers. Therefore, the alder tree distribution of Kushiro Mire is closely related to the agricultural land area around Kushiro Mire.

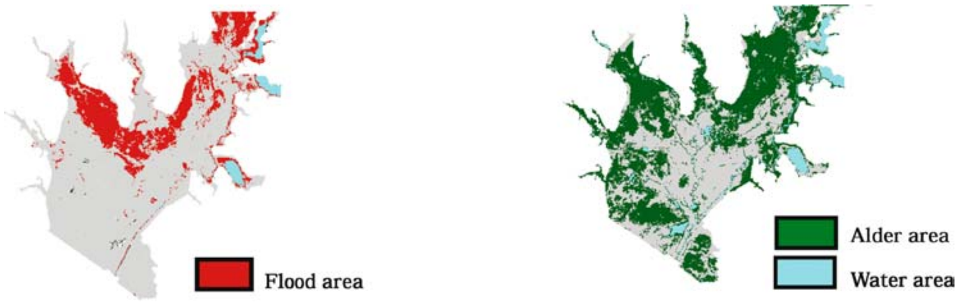
3.3. PREDICTION OF EXPANDING ALDER-TREE AREA IN KUSHIRO MIRE

From the findings described in Figures 2 and 4–6, the mechanism of the expansion of alder-tree area in Kushiro Mire can be summarized as follows.

(1) The agricultural land area in the upper course of the Kuchoro and Setsuri River basins has expanded.
(2) The eroded soil from the agricultural land located in the upper course of the Kuchoro and Setsuri River basins has been flowing into the respective rivers.
(3) Flooding has been occurring in the lower course of the Kuchoro and Setsuri Rivers as a result of the construction works to improve the drainage of agricultural land located in the rivers' upper courses.
(4) Soil sediments have been flowing into the Kushiro Mire from the north due to flooding.
(5) Consequently, the number and density of alder trees have increased because the sedimentation and accumulation of soil favor its growth.

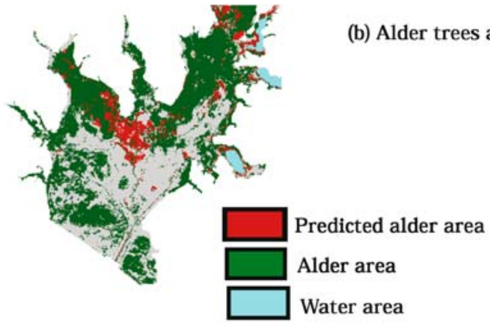
On the basis of the mechanism of expansion of the alder tree in the area of Kushiro Mire, the future distribution of alder trees was estimated from the flood area. Therefore, it is necessary to spatially observe the extent of flooding in Kushiro Mire. However, as it is difficult to evaluate the extent of flooding using Landsat MSS or TM imagery because of revisit interval of 16 days, which also hinders the assessment of flood dynamics even in relatively cloud-free areas, we cannot be certain that the extent of flooding is accurately evaluated by Landsat imagery.

In this study, the future distribution of alder trees was estimated by overlaying the flood imagery observed on 17 May 1994 with the alder trees imagery observed on 22 September 2000. Landsat imagery of 17 May 1994 showed the most widely flooded area among the images collected from 1979 to 2000. Thus, it is predicted that the flood area in Kushiro Mire, with the exception of the alder-tree area in 2000, will eventually change to alder-tree area. Figure 7 shows the future distribution of alder trees predicted from the overlaid images in Kushiro Mire. In Figure 7, areas with red color show the region that will eventually be changed to areas with alder trees at the least. It was found that large vegetation areas such as reeds and sedge grasses in Kushiro Mire will change to areas with alder trees. Furthermore, because the coverage of the evaluated flood area may not maximally expand, it should be considered that the large vegetation area in Kushiro Mire shown in Figure 7 may be underestimated.



(a) Flood area in 1994.

(b) Alder trees area in 2000.



(c) Alder area predicted using (a) and (b).

Figure 7. The future distribution of alder trees predicted from the overlaid images in Kushiro Mire.

4. Conclusions

The relationship between the alder (*Alnus japonica*) distribution and the surrounding land use was assessed using Landsat imagery with an objective of evaluating the effects of the surrounding environmental changes on Kushiro Mire. On the basis of the analytical results from the Landsat imagery, the expanding mechanism of the alder-tree area in Kushiro Mire was characterized as follows.

(1) The agricultural land area in the upper course of the Kuchoro and Setsuri River basins has expanded.
(2) The eroded soil of the agricultural land located in the upper course of the Kuchoro and Setsuri River basins has been flowing into the respective rivers.
(3) Flooding has been occurring in the lower course of the Kuchoro and Setsuri Rivers as a result of the construction works to improve the drainage of agricultural land located in the rivers' upper courses.
(4) Soil sediments have been flowing into the Kushiro Mire from the north due to flooding.
(5) Consequently, the number and density of alder trees have increased because the sedimentation and accumulation of soil favor its growth.

Furthermore, the future distribution of alder trees was predicted by overlaying the flood imagery observed in 1994 with the alder trees imagery observed in 2000. As a result, it was found that large vegetation areas such as reeds and sedge grasses in Kushiro Mire will change to areas with alder trees.

Lastly, this study concluded that the use of remote sensing techniques is generally effective for areas like Kushiro Mire, which is a difficult region to evaluate through field survey because of expansive areas with various land cover types.

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