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# Land Use/Cover Changes in Hokkaido Wetlands, Yufutsu Mires as a Case Study

ZHOU Jin[1,2] and Hisako TACHIBANA[2]

[1] Wuhan Institute of Botany, the Chinese Academy of Sciences, Wuhan 430074, China
[2]Biological Laboratory, Asahikawa Campus, Hokkaido University of Education, Asahikawa, 070-8621, Japan

# 北海道勇払湿原の土地利用 ・ 被覆変化

周　進[1,2] ・ 橘　ヒサ子[2]

[1]中国科学院武漢植物研究所 ・ [2]北海道教育大学旭川校生物学研究室

## Abstract

A raster-based GIS technique and 1:50,000 topographic maps of seven periods since 1896 were used to study land use/cover changes in Yufutsu Mires (324 km2, with 5583 meshes of 250 m × 250 m in size), Hokkaido, Japan.

In 1896, the top three land covers were broad-leaved forest, rough land and wetland. In 1998, the top three land uses were rough land, urban area, and paddy field. During the past century, the largest land use/cover changes were reduction of wetland and broad-leaved forest, the loss rates of which were 87.2% and 74.0%, respectively. Meanwhile, urban area and rough land expanded to 3.54 and 0.18 times larger than their original scales, respectively. Paddy field expanded to 3.17 times of its original area from 1919 to 1944, and remained unchanged in area since then. Dry field increased rapidly during 1953 and 1972, and later decreased. In 1998, it was only 47.5% of its peak area. Thanks to afforestation projects, coniferous forest increased since 1972, though its ratio was quite low among all the land use/cover types. A 5.54-time increase of sea area was a result of dredging of canal and opening of the modern Tomakomai Harbor. Sands and sand dunes reduced slightly, whereas river and lake, and *Sasa*-grassland nearly unchanged in size. An extremely high ratio of paddy field and low ratios of *Sasa*-grassland and coniferous forest made land uses in Yufutsu Mires different from those in Sarobetsu Mire. The number of land use/cover types per grid increased from 1.67 in 1896 to 2.64 in 1972, indicating fragmentation of landscape. High change rates of the wetland occurred during 1896-1919 and during 1953-1972, the former was caused by transferring wetland to paddy field, whereas the later by transferring wetland to rough land and urban area. Change rate of rough land was significantly high during 1972 to 1985, and later lowered down. It reached approximately 30% of the total area in 1998. Change rate of urban area increased since 1972, indicating an acceleration of urbanization. As distance from cities/

towns increased, the percent of urban area and paddy field decreased, whereas those of broad-leaved forest, dry field, wetland, and rough land increased. Four kilometers seemed to be a threshold for area percentages of urban area and paddy field.

**Keywords:** GIS, Land use/cover change (LUCC), urbanization, wetland, Yufutsu Mires

## Ⅰ. Introduction

Lowland wetland always tended to be reclaimed first when humans colonized a new land. Land use/cover changes in coastal wetlands (Cowan & Turner, 1988; McCreary et al., 1992; Liu & Cameron, 2001; Grove et al., 2001) and urbanization in wetlands (McCreary et al., 1992; Bernert et al., 1999; Grove et al., 2001; Wang & Moskovits, 2001) have drawn great interests from researchers in recent decays. Pinder & Witherick (1990) stressed the impact of urbanization on wetlands in Japan after World War II. Hokkaido contains 90% of the wetland area of Japan, and was the latest in the country to be reclaimed by humans since the Meiji Era. By far, the land use/cover changes in some main Hokkaido wetlands, such as Ishikari Mire (mainly changed to arable land, c.f. Kohyama et al., 1995[a, b]; Miyaji et al., 1995), Kushiro Mire (mainly to meadow, c.f. Agriculture, Forestry and Fisheries Council Secretariat, 1995), and Sarobetsu Mire (mainly to meadow, c.f. Zhou & Tachibana, 2002), have been studied. The main change in land use in the above-mentioned wetlands was from wetland/rough land to arable land/dairy industry land. Yet land use/cover change and local development of coastal mires in Yufutsu plain ( it is called Yufutsu Mires in the present paper) experienced urbanization and shrinkage after World War II and after the collapse of the bubble economy in 1980s-1990s, which was significantly different from the above-mentioned wetlands.

The objectives of this paper are: 1) to reveal and display land use change in Yufutsu Mires since 1896; 2) to find the relationship between land use change and distances from cities.

## Ⅱ. Methods

Lying in central Hokkaido and facing the Pacific Ocean, Yufutsu Mires consist of several coastal fen mires of an area about 1506 ha (Fujita et al., 1997) (Figure 1). The wetland area remained at 21% in 1985 since 1953 (Yabe, 1997). Humans have occupied this area since as early as 1185. It later developed into a middle-sized city because of its position to be a good harbor (Takakura & Horie, 1975, 1976, 2001). The vegetation of Yufutsu Mires was studied by Ito et al. (1978), Tachibana et al. (1978), Tachibana & Ito (1981), and Yabe & Onimaru (1997[a, b]).

### 1. Data source

Four 1:50,000 topographical maps (Chitose, Hayakita, Tomakomai and Mukawa), published in seven periods since 1896 by the Geographical Survey Institute, were selected for the study (Table 1). A raster-based GIS was conducted in the present study. Mesh method was employed to analyze land use data based on latitude and longitude: for latitude, 80 grids per 10’ (231.38m per grid); for longitude, 80 grids per 15’ (251.01m per grid) (referred to as 250m mesh in this paper). The grid size (pixel) was 58,078$m^2$. The total study area (the wetland and the watershed, lower than 20 m in altitude) was 324.25$km^2$.

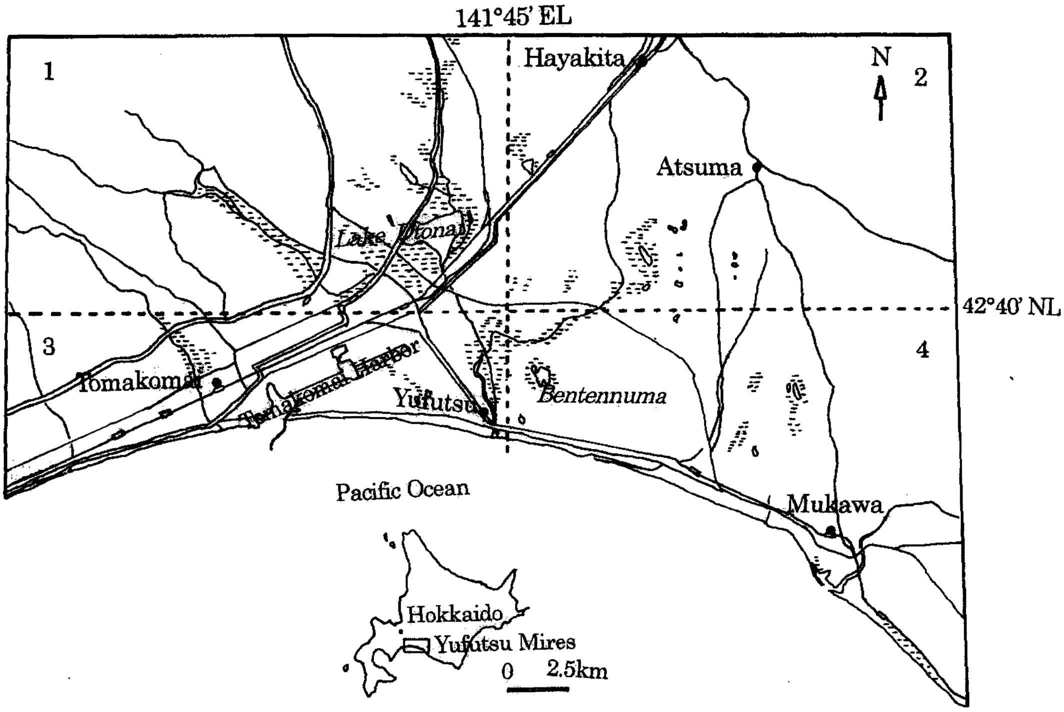


**Figure 1** Location and the geographic map of the study area (A part of topographical map of Tomakomai (1:200,000) published by Geographical Survey Institute is used).
Names of 1:50,000 geographic maps: 1. Chitose; 2. Hayakita; 3. Tomakomai; and 4. Mukawa

**Table 1** Topographical maps (1:50,000) and their publication years used in the present paper.

| Period | Chitose | Hayakita | Tomakomai | Mukawa |
|---|---|---|---|---|
| 1 | 1896 | 1896 | 1896 | 1896 |
| 2 | 1918 | 1919 | 1919 | 1919 |
| 3 | 1944 | 1944 | 1944 | 1944 |
| 4 | 1953 | 1953 | 1953 | 1953 |
| 5 | 1972 | 1972 | 1972 | 1972 |
| 6 | 1985 | 1984 | 1985 | 1985 |
| 7 | 1998 | 1998 | 1998, 1999* | 1998 |

*Two maps (Tomakomai and Yufutsu) of 1:25,000 scale.

## 2. Land use types

Twelve land use types were distinguished in the study area: 0) sea (located at the upper-left corner of grids); 1) wetland; 2) paddy field; 3) dry field (including meadow and pasture); 4) *Sasa* grassland; 5) coniferous forest; 6) broadleaved forest; 7) river and lake; 8) urban area; 9) rough land; 10) sand dune; and 11) others. When summarizing, land use types 4), 5), and 10) were so small in area that they were further grouped into type 11).

One city (Tomakomai, X-coordinate 32nd grid, Y-coordinate 66th grid) and four towns (Yufutsu, X75, Y62; Mukawa, X140, Y35; Hayakita, X104, Y127; Atsuma, X125, Y107. Figure 1) were chosen to detect the relationship of land use/cover change to distance from cities/towns, both because of their scales and their long history of establishment. The sites of cities/towns in the area were orientated according to the most recent maps (1998). Distances from cities/towns were divided into six grades: 1) 0 to 2 km; 2) 2 to 4 km; 3) 4 to 6 km; 4) 6 to 8 km; 5) 8 to 10 km; and 6) further than 10 km.

Data were input as Microsoft Excel files according to Himiyama et al. (1990) method. ArcView GIS 3.2a and ArcView Spatial Analyst 2.0a (ESRI Inc.) was used for mapping. For wetland loss rate and land use/cover change of wetland, the wetland data in 1919 was adapted in calculation, because that in 1896 was lower due to improper land use marking and an incomplete field survey. For details of the calculation, consult to Zhou & Tachibana (2002).

## Ⅲ. Results

### 1. Land use/cover maps

In 1998 (the latest) map, 5,583 grids were obtained (324.25km$^2$), whereas those in 1896 (the earliest) map were 5,544 grids. The relative error was 0.007%, which was much lower than Zhou and Tachibana (2002). Figure 2 displays the land use maps of all seven study periods, and Figure 3 is a summary of land uses of each period. In 1896, the top three land covers were broad-leaved forest (35.79% of the study area), rough land (27.16%), and wetland (25.92%. The value was 30.45% in 1919). Urban area was only 5.01%, and no paddy field or dry field appeared. Amazingly, paddy field was developed to 5.07% in 1919, and to its maximum 16.08% in 1944. It maintained its high ratio at approximately 15% during the successive years. This agreed with the change pattern of paddy field in all-round Hokkaido (Himiyama, 2002). The percent of dry field was always lower than that of paddy field except in 1972 when dry field reached its maximum (15.31%). An extremely high ratio of paddy field and extremely low ratios of *Sasa*-grassland and coniferous forest made land uses in Yufutsu Mires significantly different from those in Sarobetsu Mire (Zhou & Tachibana, 2002).

In 1998, the top three land uses were rough land (31.95%), urban area (22.59%), and paddy field (15.57%). Broad-leaved forest and wetland, which were among the top three in 1896, decreased to 9.24% and 3.90%, respectively. During the past century, the largest land use/cover changes were reduction of wetland and broad-leaved forest, the loss rates of which were 87.2% and 74.0%, respectively. Meanwhile, urban area and rough land expanded to 4.54 and 1.18 times larger than their original scales, respectively. The increase rate of urban area was yet much lower than that in all-round Hokkaido (12.25 times) (Himiyama, 2002). Thanks to afforestation projects, coniferous forest increased since 1972, though its ratio was quite low among all the land use/cover types. A sudden increase (5.54 times) of sea area (Type 0) during 1953-1972 was a result of dredging of canal and opening of the modern Tomakomai Harbor in 1963 (Takakura & Horie, 1975, 1976, 2001). Sands and sand dunes reduced slightly, whereas river and lake, and *Sasa*-grassland nearly unchanged in size.

The urban area experienced its first reduction (6.62% reduce in area) during 1944-1953, because of World War II. Traces were found in the maps and from annals. For example, the first airport in this area (Hibarinooka Airport) was put into usage in 1927. In Numanohata, a *keibajyou* (race-course) was used as an airport between 1936 and 1944 for military purpose (Takakura & Horie, 1975, 1976, 2001). In the 1953

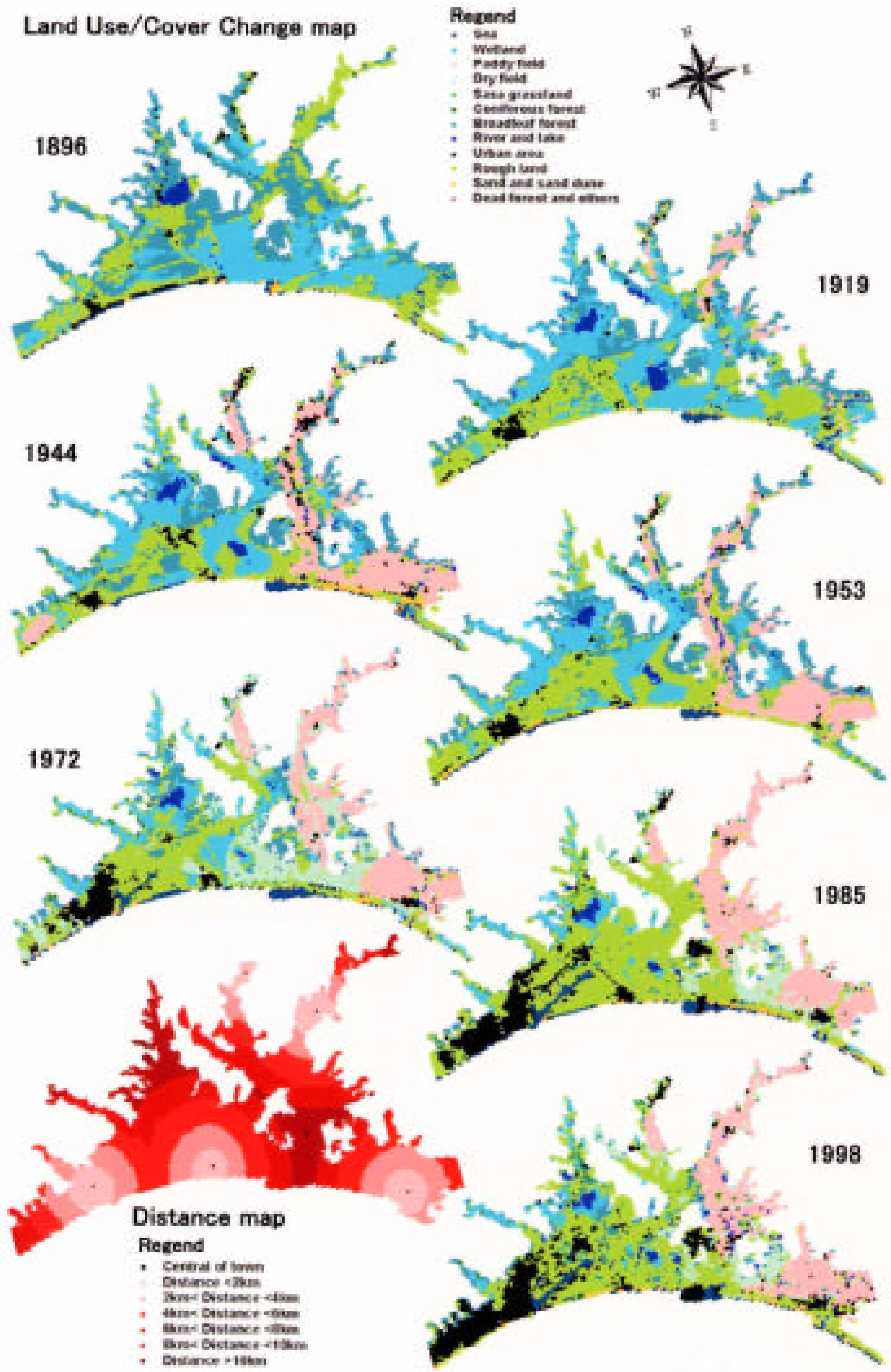


**Figure 2** Land use/cover maps of Yufutsu Mires in the seven studied periods and a map showing distance from cities/towns (One grid equals to 250m × 250m).

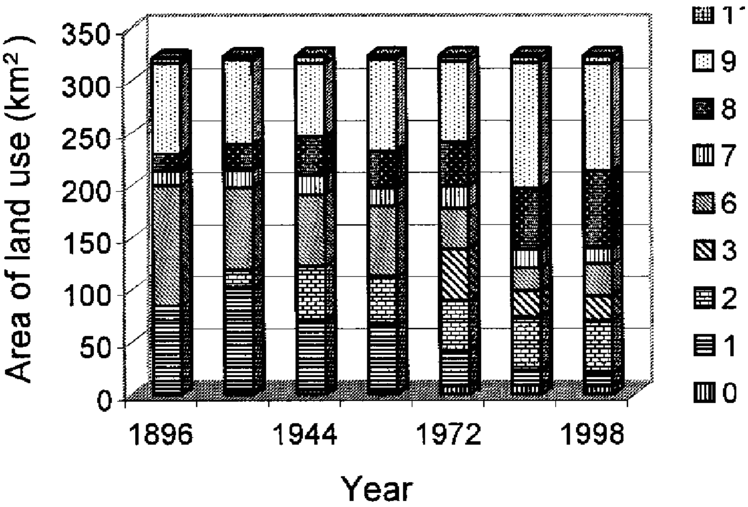


**Figure 3** Percentages of land use/cover in Yufutsu Mires from 1896 to 1998.
Land use/cover types: 0. Sea; 1. Wetland; 2. Paddy field; 3. Dry field (including meadow and pasture); 4. *Sasa* grassland; 5. Coniferous forest; 6. Broad-leaved forest; 7. River and lake; 8. Urban area; 9. Rough land; 10. Sand and sand dune; and 11. Dead trees and others.

map, it was abandoned as rough land, with a contour of the runways. It disappeared completely in later maps. Instead, a big airport was built in New Chitose, another city north to the study site, and nearer to Sapporo City, the capital of Hokkaido. A second reduction of urban area was not detected by map analysis, although it was likely to happen after the bubble economy in Japan collapsed in 1992. Actually, large blocks of land to be developed into industrial areas were abandoned to rough land since then (Himiyama, 1999, 2002; Miyawaki, 1999; Hokkaido News Agency, 1999).

Type number of land use per grid varied among the studied periods (Table 2). It increased from 1.67 types per grid in 1896 to 2.64 types in 1972, and then declined. The change pattern was much similar to that in Sarobetsu Mire (Zhou & Tachibana, 2002).

**Table 2** Type numbers and change rates of land use/cover in Yufutsu Mires.

**Figure 5** Land use/cover changes in relation to distance from cities/towns.
1.0 to 2 km (41 km$^2$, occupying 13% of the total area); 2. 2 to 4 km (70 km$^2$, 22%); 3. 4 to 6 km (85 km$^2$, 26%); 4. 6 to 8 km (82 km$^2$, 25%); 5. 8 to 10 km (44 km$^2$, 14%); and 6. further than 10 km (1 km$^2$, 0.5%). For land use/cover types 0-11, see those in Figure 3.

**Table 3** Land use/cover change of wetland in Yufutsu Mires from 1919 to 1998.

### 2. Land use/cover change maps

Land use/cover change maps were created both by period and by land use/cover type (Figure 4). High change rates occurred during 1896-1919 (66%) and during 1953-1972 (67%), whereas low rates occurred during 1944-1953 (43%) and during 1985-1998 (40%) (Table 2). This is consistent with the result of Sarobetsu Mire (Zhou & Tachibana, 2002). The two stages with high change rates of the wetland were caused by transferring wetland to paddy field, and by transferring wetland to rough land and urban area, respectively. The total change rate from 1896 to 1998 was 99%. The relatively high change rates may be caused by methodology: a slight shift when sampling from the upper-left grid of map might result in big different of land use.

Close attention was paid to land use/cover changes of the wetland from 1919 (Table 3), large proportions of formal wetland changed into rough land (44.60%) and urban area (18.04%), whereas relatively low proportions were changed into paddy (9.34%) and dry (7.81%) fields, two agricultural land uses. This is opposite to the wetland in the Willamette Valley, Oregon, USA (Bernert et al., 1999). The remaining wetland in Yufutsu Mires was only 7.23% of the original. This value was obviously lower than that (12.82%) calculated from Figure 3, because during 1919 and 1998, although wetland changed into other types of land use/cover, other types also changed into wetland, which were not taken into account in this section.

The last change of land use/cover and happening years is listed in Table 4. The earlier a period was, the less last change happened. Approximately 40% of last changes happened in 1998. By checking land use/cover types, the top types last changed into were rough land (31%), urban area (21%), broad-leaved forest (13%), and paddy field (12%).

### 3. Land use/cover change in relation to distance from cities/towns

As distance from cities/towns increased, percents of urban area and paddy field decreased, whereas those of broad-leaved forest, dry field, wetland, and rough land increased (Figure 5). Four kilometers seemed to be a threshold: percents of urban area and paddy field were much higher within the range than those beyond. Percent of river and lake did not change with period or distance.

## Ⅳ. Discussion

### 1. Impacts of urbanization on wetlands

Land use/cover change in urbanizing wetlands can significantly alter the hydrology of a watershed and can have a serious impact on wetland vegetation, water balances, downstream flooding, and groundwater

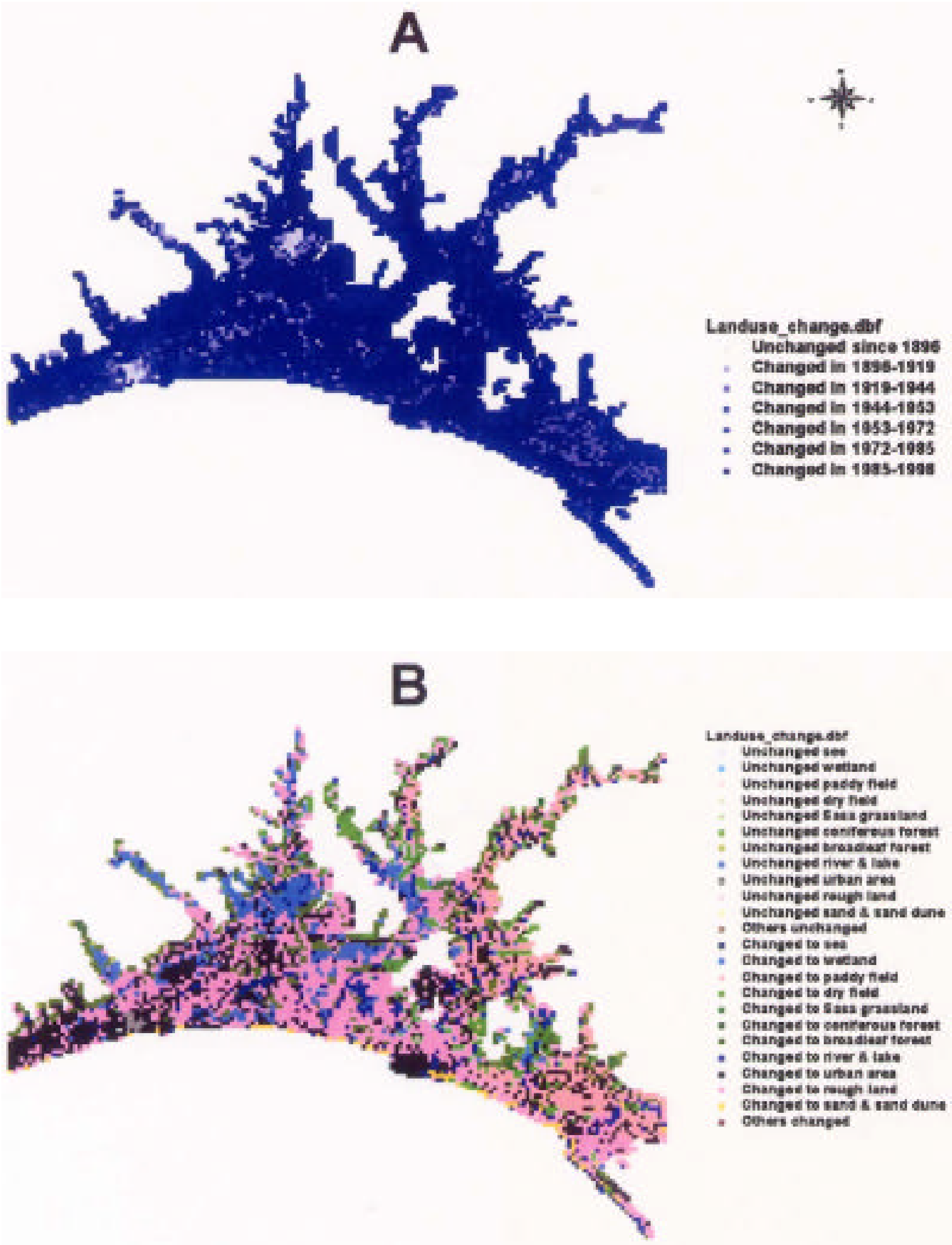


**Figure 4** Maps of land use/cover changes of Yufutsu Mires (One grid equals to 250m × 250m). A by period; B by land use/cover type.

**Table 4** Land use types (%) last changed from other types and happened years.

recharge (Grove et al., 2001). The most direct impact is on wetland habitats and stream environments, and an indirect impact is from nonpoint-source pollutant loading (McCreary et al., 1992). Regional differences in land loss and wetland loss reflected variations in geology and the deltaic growth/decay cycles, man-induced changes in hydrology (principally canal dredging and spoil banking), and land use/cover changes (principally urbanization and agricultural expansion) (Cowan & Turner, 1988). In Galveston Bay wetlands, Texas City, an area of high disturbance, experienced a change in wetland composition, whereas Anahuac, an area of medium disturbance, experienced changes in both wetland composition and abundance (Liu & Cameron, 2001). In Greater Chicago, the rapid acceleration of urban and suburban areas sprawled over the past 12 years. Patterns of land use/cover change and their effects on the vitality of communities under threat were evaluated. The data on habitat degradation and fragmentation were biological foundation of quantitative goals for regional wetland restoration (Wang & Moskovits, 2001).

In the study site of the present paper, the urban area has quadrupled during the past century, which may have suffered more severe problems than the above mentioned wetlands. The main problem in Yufutsu Mires is drainage and reduction of wetland and thus habitat loss for wildlife because of urbanization: it was a corridor for brown bears to move between the two adjoining forests of the mires; and it was a territory for migrant water fowls (Hokkaido News Agency, 1999). Urban reduction of the area has resulted in an increase of rough land, rather than wetlands, which indicates that urban reduction in a formal wetland will not necessarily restore the disturbed wetland automatically. Urbanizing of wetland has changed nearly all environmental variables of the wetland.

**2. Some problems in land use in Hokkaido wetlands and their possible solutions**

Hokkaido, occupying over 90% of the wetland area of Japan, lost 53% of the wetland during ca. 1920 and ca. 1985 (Himiyama, 2002). After more than one century’s reclamation on wetlands, some serious problems occurred, such as ground subsidence, flooding, silt sedimentation, fragmentation and drought of wetland, *Sasa* expansion, natural afforestation in wetland core area, severe eutrophication, climatic deterioration, etc. In many of the Hokkaido wetlands, wastewater of livestock farm and barnyard manure has caused severe eutrophication (Agriculture, Forestry and Fisheries Council Secretariat, 1995). Agricultural reclamation continued to be the most serious threat to the wetlands in Hokkaido (Himiyama, 2002).

In Ishikari peatland, the area of mire had decreased from 550 km$^2$ at 1870s to 0.3 km$^2$ at 1980s. About half of fens were reclaimed and used as upland fields until 1910s, and half of bogs were reclaimed as paddy fields during 1950s to 1960s. The main land use change was first developing to paddy field, then transferring paddy field to dry field. After about 30 years of development, three meters of ground subsidence occurred in dry field by decomposition of peat, which needs a large amount of soil for top-dressing; in paddy field, ground subsidence also causes flooding disaster (Yano et al., 1980; Sakuma, 1991; Kohyama et al., 1995[a, b]; Miyaji & Kohyama, 1997; Agriculture, Forestry and Fisheries Council Secretariat, 1995).

In Kushiro Mire, fen of the upper part and the surrounding area of the mire were reclaimed into meadow; the lower part of the mire was urbanized. Only 2.6% of the mire was lost from 1955 to 1983. The core mire remained as the National Park and a Ramsar wetland (Agriculture, Forestry and Fisheries Council Secretariat, 1995). But short cutting of a river course caused silt sedimentation, and drainage of the wetland caused natural afforestation (of alder swamp forest) in the core of the national park (Nature Conservation Bureau, Environmental Agency, 1993[a]; Agriculture, Forestry and Fisheries Council Secretariat, 1995, 2000).

In Sarobetsu Mire, continuous land reclamation resulted in wetland loss of 70% during 1923 to 1996 (Fujita, 1997; Zhou & Tachibana, 2002). Drainage for meadow development lowered the ground water of the wetland, which caused invasion of *Sasa*, a dwarf bamboo, into the core of the park (Hokkaido Developmental Agency, 1972; Ito, 1983; Umeda et al., 1988; Ito & Wolejko, 1990; Nature Conservation Bureau, Environmental Agency, 1993[b]; Tachibana, 2002).

As rice production has exceeded the consumption rate since the 1970s in Japan, and as awareness of environmental conservation grows, it is possible to withdraw some paddy fields in Hokkaido, and restore the former wetlands. A buffer zone between reclaimed area and remained wetland is necessary to ease up habitat changes or de-eutrophication. *Alnus japonica* forest, *Phragmites austlaris*, and *Spiraea salicifolia* community in fens are natural buffer zones in Hokkaido (Agriculture, Forestry and Fisheries Council Secretariat, 2000). The reconstruction of buffer zones between reclaimed area and remained wetlands are necessary (Tachibana, 2002). Mowing or cattle grazing might be a solution to the *Sasa* problem in Hokkaido. A damming-up project of ground water by partition sheet might be an effective way to restore the reclaimed wetland and to prevent *Sasa* invasion (Nature Conservation Bureau, Environmental Agency, 1993[b]), though it might cause invasion of *Phragmites*, or cause vegetation change.

## Ⅴ. Acknowledgements

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## 要　旨

ラスターGISの手法と1896年以降7期の国土地理院発行5万分の1地形図を用いて，道央太平洋沿岸に位置する勇払平野湿原群（この論文では勇払湿原とよぶ）の土地利用・被覆変化を解析した．調査対象地の面積は324km$^2$，1辺250ｍのグリッド数は5583個である．1896年の土地利用・被覆面積で大きいものは落葉広葉樹林，湿地及び荒地であったが，1998年には都市域，水田及び荒地であった．過去100年間における土地利用・被覆変化では湿地と落葉広葉樹林の減少が最も大きく，その減少率は前者で87.2%，後者で74.0%であった．それに対して，都市域は4.54倍，荒地は1.18倍に増加し

た．水田は1919から1944年の間に3.17倍に増加したが，その後変化していない．畑地は1953年から1972年にかけて急激に増加したが，その後減少し，1998年の残存率は47.5%であった．針葉樹林の割合は全体的に小さいが，1972年以降，年々増加している．これは植林事業の進展によるものと考えられる．また，近陸海面も5.54倍に増加しており，港湾整備が進んでいることを示している．砂浜・砂丘はやや減少したが，河川とササ草原にはほとんど変化がなかった．勇払湿原では水田の割合が著しく高く，ササ草原と針葉樹林の割合が低い点でサロベツ湿原とは大きく異なっていた．

グリッド当たりの土地利用・被覆タイプの数は1896年から1972年にかけて1.67から2.64に増加し，景観の断片化が進んだ．湿地の変化率が高かった時期は1896～1919年と1953～1972年の２回あり，前者は湿地から水田への転換，後者は湿地から荒地と都市域への変化であった．荒地の変化率は1972年から1985年にかけて著しく高くなり，その後やや減少したが，1998には全面積の約30%に達した．都市域は1972年以降の変化率が高く，都市化の進展が示された．市街地からの距離が遠くなるほど都市域と水田が減少し，落葉広葉樹林，畑地，湿地，荒地が増加した．都市域と水田域の広がりは4 km以内であった．

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* In Japanese.

** In Japanese with English summary.