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Evaluation of Peatland in Northern Japan in Terms of Land Subsidence

Naomichi MIYAJI, Kazunori KOHYAMA* and Hiroo OTSUKA**

Department of Agro-Environmental Sciences, Hokkaido National Agricultural Experiment Station (Sapporo, Hokkaido, 062 Japan)

Abstract

Studies were carried out to identify a method of constructing a peatland evaluation map based on forecasting data of land subsidence of arable peatland in northern Japan. Land subsidence in a district here has become a serious problem due to the increase in the area of upland fields converted from paddy fields. First, we estimated the present rate of land subsidence based on the measurement of land elevation and soil survey, and determined the degree of decomposition of peat in marshlands, windbreak forests and arable lands in the Ishikari peatland in northern Japan. Second, we evaluated the sustainability of arable peatland based on data of actual land subsidence and other parameters, and we compiled an evaluation map of Ishikari peatland using geographical information systems (GIS). Soil type, period of land development, present land use and thickness of top-dressed soil were selected as main factors for the evaluation, and scores of elements of each factor were determined. According to the total scores, sustainability of arable peatland was divided into 3 classes. A land evaluation map of Ishikari peatland in terms of land subsidence was compiled using these classes.

Discipline: Agricultural environment/Soils, fertilizers and plant nutrition
Additional key words: decomposition of peat, geographic information system, Histosols, land use

Introduction

Histosols, the organic soil of peatlands, cover about 240 million ha worldwide[1], of which about 213 million ha are distributed at latitudes higher than 40° N[2]. Peatlands have been utilized for agriculture for 19 centuries in Europe and more recently in Asia.

Total area of peatlands in Japan is about 500 thousand ha, of which 236 thousand ha are distributed in Hokkaido, Japan's northern large island[10]. The Ishikari peatland, the largest such land in Hokkaido (60 thousand ha), has been cultivated and used mostly as arable land (Fig.1). Subsidence of this peatland has continued after reclamation, as in the case of other peatlands of the world. The rate of subsidence became particularly accelerated due to the increase in the area of upland fields converted from paddy fields. This conversion scheme from peatland was associated with the rice production adjustment program initiated in 1970[5].

For agricultural use, it is necessary to alleviate soil acidity and to decrease the groundwater level. As a result, the subsidence of agricultural peatlands due to shrinkage, consolidation, and decomposition of peat has occurred and caused serious problems in the management of agricultural fields, including growth inhibition of crops by rising groundwater level, destruction of agricultural facilities and unevenness of fields[3,13]. Previous studies on Histosols and on peatland have focused mainly on the improvement of physico-chemical properties to increase productivity, promotion of drainage for the stability of the reclaimed fields, and use of peat as a resource. Consequently, few studies on the land use and subsidence of peatland have been carried out[12].

It is anticipated that agricultural fields, constructed over a long period of time at a high cost, may be lost by progressive subsidence. Consequently, ade-

Present address:
* Upland Agriculture Research Center, Hokkaido National Agricultural Experiment Station (Memuro, Kasai, 099–61 Japan)
** Department of National Resources, National Institute of Agro-Environmental Sciences (Tsukuba, Ibaraki, 305 Japan)

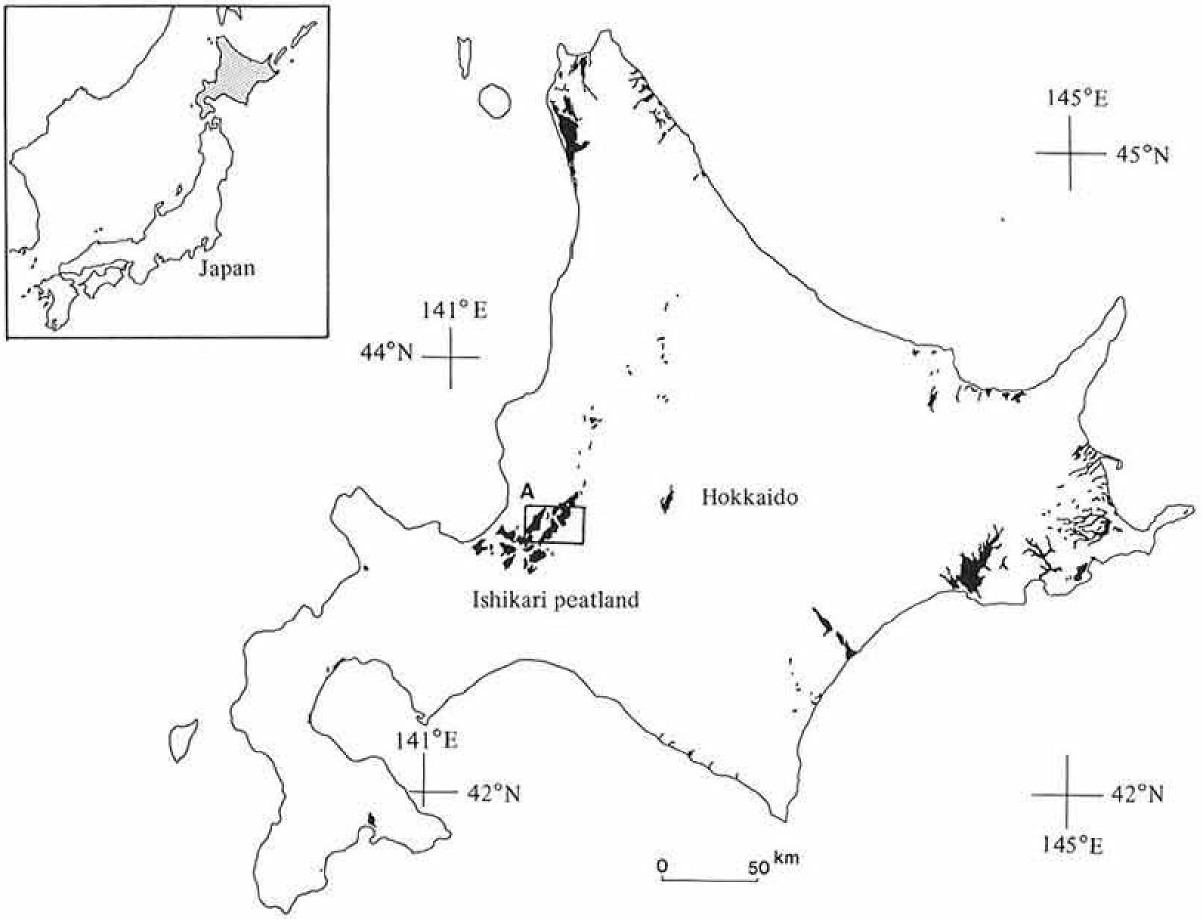

Fig. 1. Location of study area (A) and distribution of peatlands in Hokkaido

quate land use and field management are necessary for the promotion of sustainable agriculture[10]. For such management, a suitable land evaluation method based on forecasting data of subsidence should be developed.

Recently, geographic information systems (GIS) have been used to analyze and evaluate multiple geographical data comprehensively[4]. By using the GIS, it is easy to construct maps for analysis and evaluation. To construct a map for the evaluation of land productivity, the procedures are as follows: (1) identify the factors limiting land productivity, (2) separate the factors into elements, (3) grade the elements according to their contribution to productivity, and (4) evaluate the land by a resulting total score. The GIS enables to evaluate peatland based on forecasting data of subsidence, which are obtained by field investigation and the results of analysis on the relation between subsidence and other factors (e.g. soil and land use).

This paper focuses on the method of constructing a sustainability map for arable peatland using the GIS and based on the criteria for forecasting the degree of subsidence.

Land subsidence of Ishikari peatland

1) Soil and land use

The soils of Ishikari peatland consist mainly of High moor peat soils (Sphagnofibrists) and Low moor peat soils (Medihemists) including lowland soils (Udifluvents, Haplaqepts and Haplaquents)[13]. Half of the area is covered with High moor peat soils which are prone to subsidence with a decrease in volume by half when they become dry[12].

Reclamation of Ishikari peatland started in the 1900s and was nearly completed in the 1960s after the national development project of this peatland. After such reclamation during the 1950s and 1960s, most of the peatland was converted to paddy fields. The degree of subsidence was more conspicuous just after the reclamation (primary subsidence) than in the 1970s, late after the reclamation (secondary subsidence)[5]. After the 1970s, considerable land

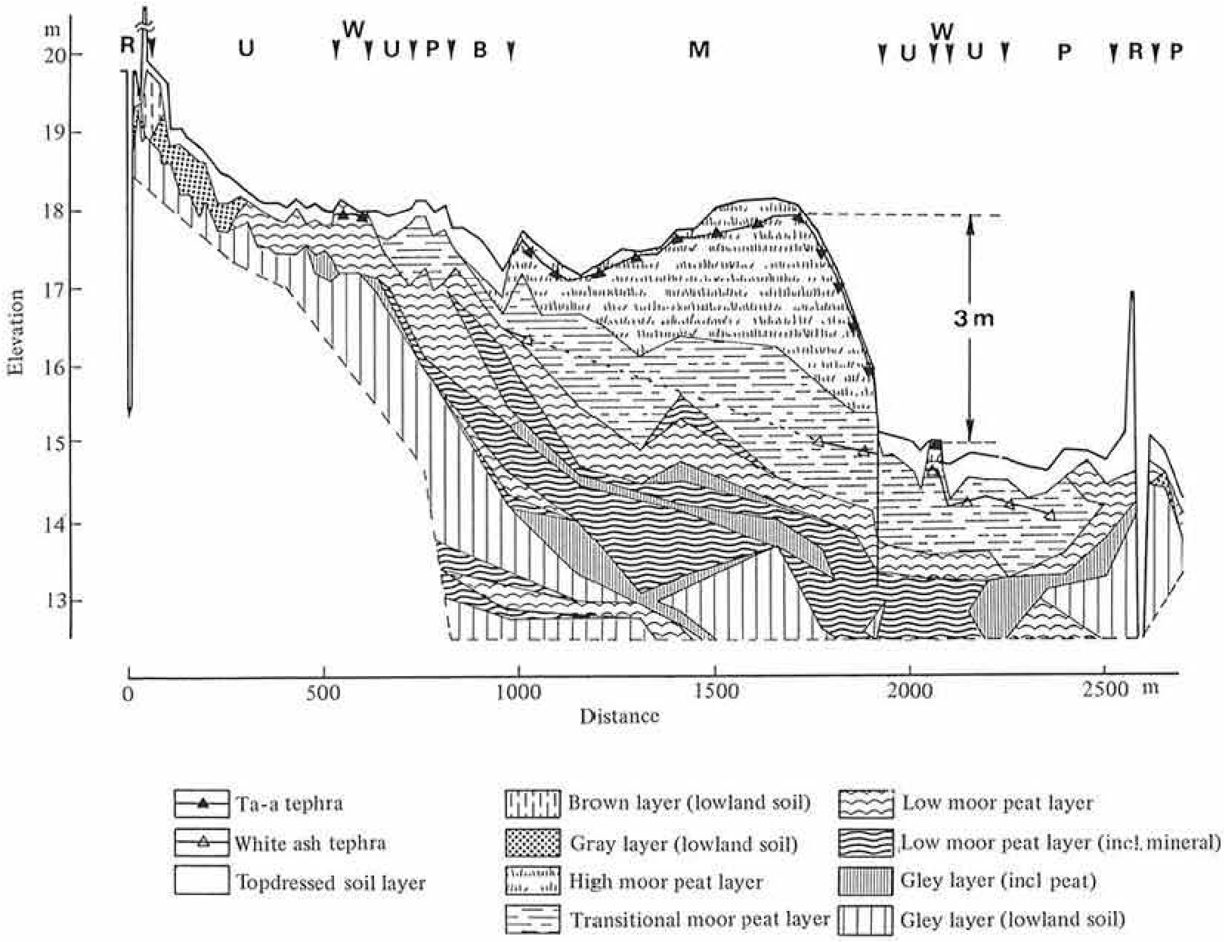

Fig. 2. Cross-section of marshland and arable peatland at Bibai, Ishikari peatland
U: Upland field, W: Windbreak forest, P: Paddy field, B: Building site, M: Marshland, R: River.

subsidence was observed again in many locations, along with the increase of the area of upland crop fields converted from paddy fields. Finally, one-third of the paddy fields was converted to upland fields in the Ishikari peatland.

2) Land subsidence after reclamation

The degree of subsidence after reclamation was calculated by comparing the topography and elevation of soil layers in a marshland and in a windbreak forest surrounded by arable peatland at Bibai, Ishikari[8]. The soils at and around the Bibai marsh consist of High moor peat soils. The surface and subsurface horizons of this area consist of High moor peat layers (*Sphagnum* peat layers) and Transitional moor peat layers (*Carex* peat layers). We can observe two volcanic ash layers in these peat layers, one upper Ta-a tephra and a lower white ash tephra. The elevation of Ta-a is 3 m higher in the marshland than in the windbreak forest (Fig. 2). The surface of this area was nearly flat in the early 1950s when reclamation started. Therefore, over a period of 40 years the windbreak forest and surrounding agricultural fields showed a subsidence of about 3 m compared to the marshland due to shrinkage, consolidation and decomposition of High moor and Transitional moor peat layers and the average rate of land subsidence for the past 40 years has been 8 cm/year. This value corresponded to the rate value calculated by comparing data from the soil survey conducted in this district before reclamation (in 1918) and after reclamation (in 1991)[8].

3) Land subsidence of converted upland fields

The rate of subsidence of upland fields converted from paddy fields was calculated based on the comparison of the topography and soil layers of uplands fields and of paddy fields that had not been converted[8]. Fig. 3 shows a cross-section of a paddy field and an upland field. This upland field (U) was

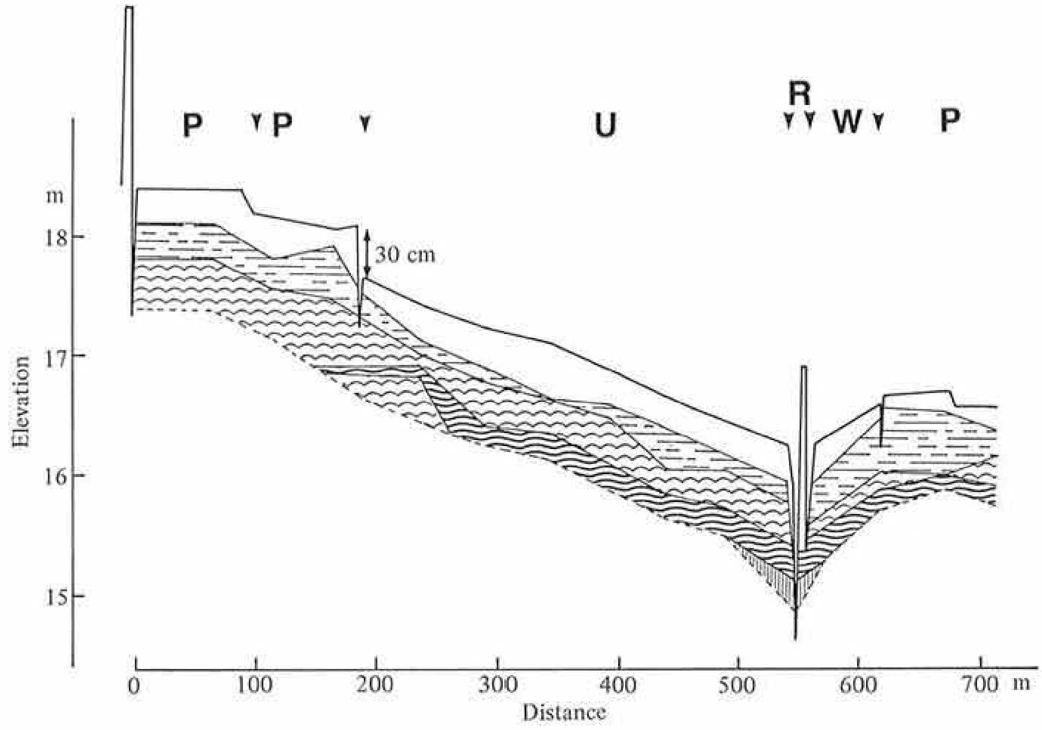

Fig. 3. Cross-section of paddy field and converted upland field at Bibai, Ishikari peatland
Figure captions are the same as in Fig. 2.

converted in 1982. Before the conversion, no obvious difference in elevation between the upland field and the paddy field was observed. The difference between the surface elevation of the upland field and the paddy field was 30 cm, based on soil survey data of 1991. The average rate of subsidence relative to paddy fields was estimated at 3 cm/y based on these data. Furthermore, the rate of subsidence of paddy fields was about 1 cm/y, and about 3 cm/y for upland fields, based on determinations by the subsidence monitoring board. Just after the conversion from paddy fields to upland fields, the rate of subsidence exceeded 3 cm/y.

The remarkable subsidence of upland fields is attributed to the following factors: (1) lower upland peat layers can shrink significantly, as the groundwater level of uplands fields is lower than that of paddy fields, (2) subsurface peat in uplands fields decomposes easily because it is mixed with top-dressed mineral soil by deep plowing every season[9]. For example, Fig. 3 shows that the thickness of the subsurface Transitional peat layer was nearly halved by deep plowing, compared to paddy fields. This decrease in the thickness of the peat layers is considered to be due mainly to the decomposition of peat associated with deep plowing of the field.

4) Decomposition of peat

Decomposition of peat is one of the main factors of subsidence. The difference in decomposition between the marshland and the windbreak forest was estimated by comparing the total organic carbon content of peat, which was packed by two tephra layers[8]. In this estimation, it is assumed that the peat layers in both land uses showed the same thickness and the same stratigraphy before the reclamation. According to this calculation, about 80% of the organic carbon decomposed in 40 years was due to the change from marshland to forest.

Land evaluation of Ishikari peatland

1) Method of land evaluation using GIS

It is important to evaluate arable peatland in terms of subsidence for the promotion of sustainable agriculture. We evaluated the sustainability of arable peatland based on forecasting data of subsidence, and compiled an evaluation map of the central part of the Ishikari peatland using the GIS[7]. Fig. 4 shows the flow chart for the preparation of the evaluation map. In the first step, published materials relating to land subsidence were collected. Soil type, land

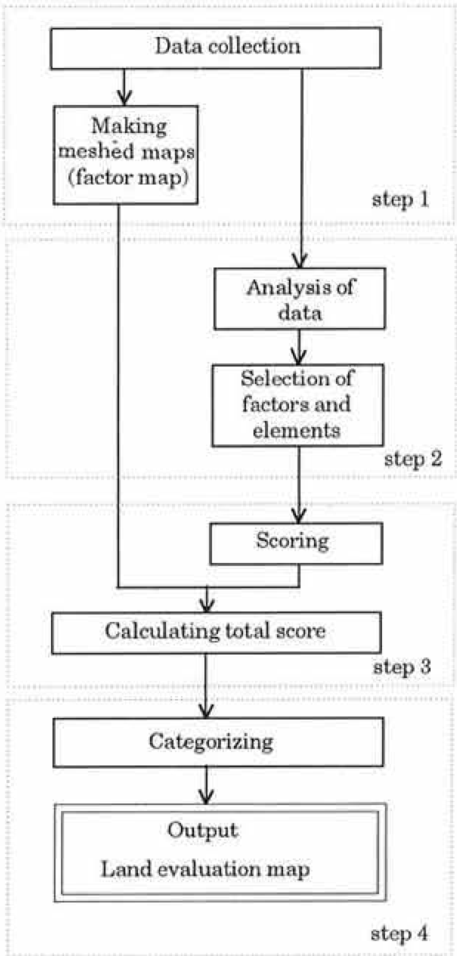

Fig. 4. Flow chart for preparation of the evaluation map

use, periods of land development and thickness of topdressed soil were extracted as main factors related to subsidence. Then the soil map, land use map, map of thickness of top-dressed layer, subsidence map and map of period of development were prepared using a 100-m grid.

In the second step, these maps were overlaid and the conditions of the occurrence of subsidence were clarified.

In the third step, scores were assigned to elements of each factor, according to their contribution to subsidence. Each factor consists of some elements related to subsidence. For example, the soil factor includes High moor peat soils, Low moor peat soils and lowland soils as shown in Table 1. After this scoring, maps related to the factors were overlaid and the total scores of these factors were calculated for each grid.

In the fourth step, the total scores were categorized and the results were presented as a land evaluation map.

2) Selection of factors for land evaluation

The relationship between the subsidence and the soil type, land use, thickness of top-dressed soil was analyzed. Based on the analysis, the degree of subsidence was found to be the largest in High moor peat soils with a high content of organic materials, followed by Low moor peat soils, and lowland soils that are mineral soils (Fig.5).

Upland fields, that were reclaimed as paddy fields in the 1960s and converted recently (WWPU type) tended to exhibit a larger degree of subsidence than the fields that had been used continuously as paddy fields (WWPP type; Table 2). These results are in agreement with the field observations previously described. Based on the comparison of different types of land use records (WWPP, WUPP and UUPP types), subsidence was more pronounced in agricultural fields reclaimed in later periods than in earlier periods[7] (Fig.6). This difference may mainly account for the fact that in the fields reclaimed earlier rapid shrinkage by drainage was no longer observed and was replaced by gradual subsidence caused mainly by the decomposition of peat.

Thinner top-dressed soil layer in upland fields showed a large degree of subsidence with the decomposition of peat when plowed and mixed with mineral soil[7]. As the depth of plowing here is 25 cm, it is likely that the subsurface peat layer may have been scraped to the surface by plowing, unless it was covered by a top-dressed soil layer of over 25 cm in thickness. The thickness of the top-dressed soil in this area was estimated at an average of

Table 1. Relation between the factors and score to construct a land evaluation map

Factors for evaluation	Element	Score
Soil type	High moor peat soils	3
	Low moor peat soils	2
	Lowland soils	1
Period of reclamation	After the 1960s	2
	Before the 1960s	1
Recent land use	Upland field	2
	Paddy field	1
Thickness of top-dressed soil	Less than 25 cm (except lowland soils)	2
	More than 25 cm (Lowland soils)	1

Table 2. Types of land use sequence from the 1910s to the 1970s at Ishikari peatland

	1910s	1950s	1960s	1970s
WWPP	Wasteland*	Wasteland*	Paddy	Paddy
WUPP	Wasteland*	Upland	Paddy	Paddy
UUPP	Upland	Upland	Paddy	Paddy
WWPU	Wasteland*	Wasteland*	Paddy	Upland

* Including marshland.

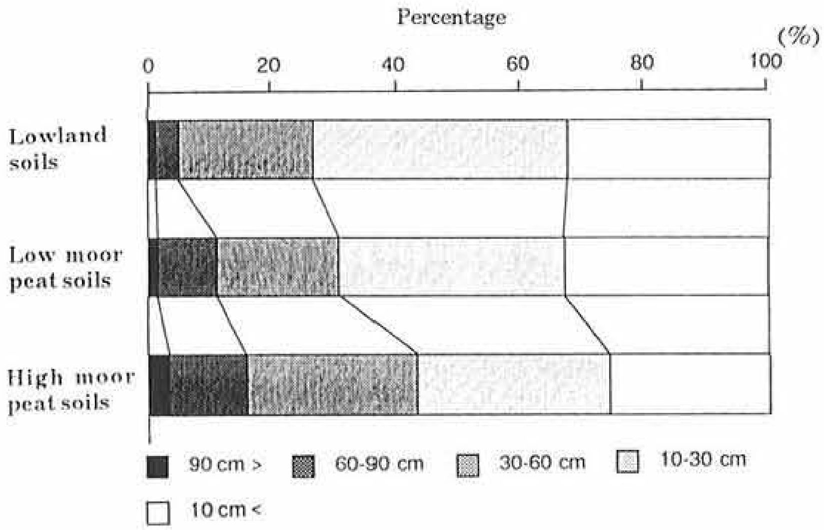

Fig. 5. Relation between the subsidence and soil type at Ishikari peatland

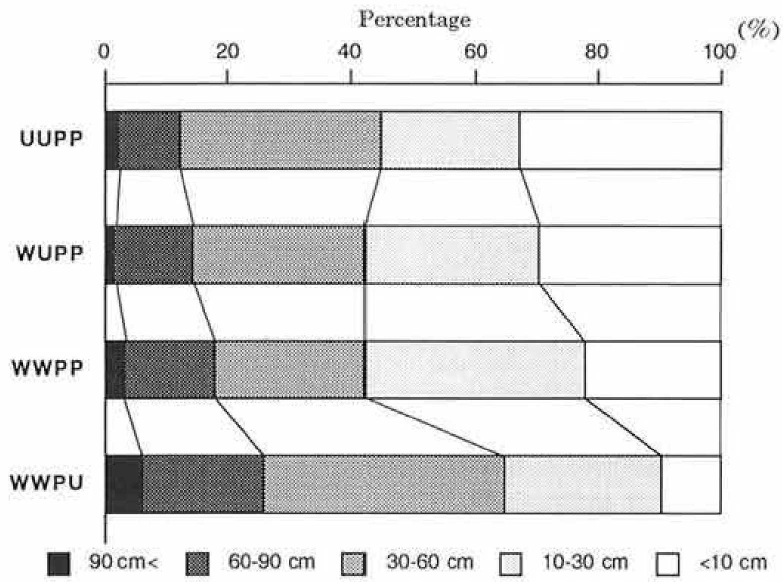

Fig. 6. Relation between the subsidence and land use type at Ishikari peatland

14 cm for High moor peat soils and 9 cm for Low moor peat soils[6].

On the basis of these results, we selected soil types (High moor peat soils, Low moor peat soils and lowland soils), period of land development (before or after the 1960s), present land use (paddy field or upland field), thickness of top-dressed soil (thick or thin) as the main factors for the evaluation.

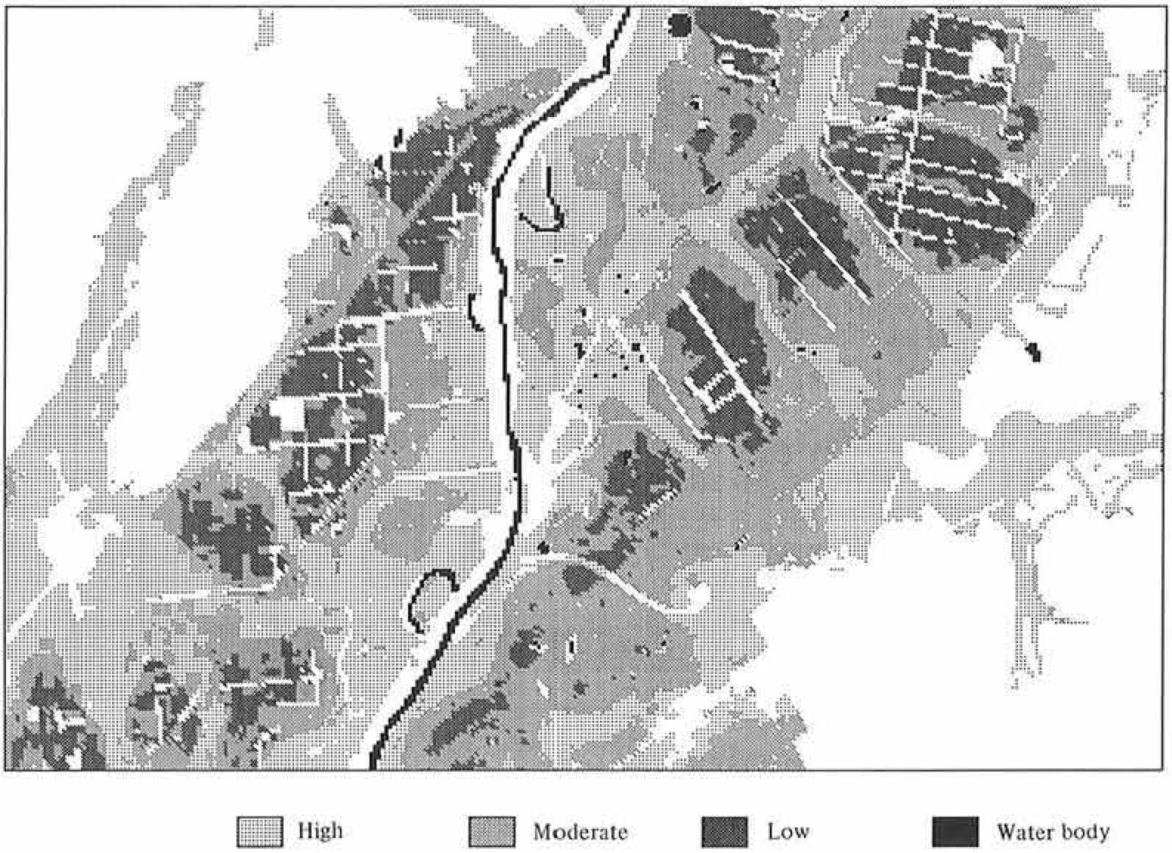

Fig. 7. Land evaluation map for sustainability of arable peatland at Ishikari peatland

3) Scoring of elements and construction of an evaluation map

The sustainability of agricultural peatland was determined by the total score of each element. The higher the score, the larger the susceptibility to subsidence. The relation between the elements and the score was as follows (Table 1): Soil type: Score of High moor peat soils was 3 points, Low moor peat soils 2 points and lowland soils 1 point, in ascending order of subsidence. Period of land development: Score of land reclaimed after the 1960s was 2 points and of the others 1 point, as the subsidence was more conspicuous in fields reclaimed earlier. Present land use: Score of upland fields converted in the 1980s was 2 points and of the others 1 point, as the subsidence was obvious in upland areas, especially in upland fields converted from paddy fields. Thickness of top-dressed soil: Score of thickness less than 25 cm was 2 points and of the others 1 point, depending on the depth of plowing. Score of lowland soils was 1 point, due to the absence of peat layer.

We calculated the total scores of elements in each factor. In this calculation, the total scores ranged from 4 to 9 points. The presence of higher scores suggests that the subsidence may increase in the near future. Based on the sum of these scores, we constructed a land evaluation map for the sustainability of arable peatland divided into 3 classes; high (4, 5 points in total), moderate (6, 7 points in total), low (8, 9 points in total)[7] (Fig. 7). Based on this classification, the area of Ishikari peatland in each category covered 15,520 ha (high), 12,430 ha (moderate), 6,040 ha (low). For the evaluation of other arable peatlands, it is important to select the factors and appropriate weighting according to each situation.

In this evaluation map, arable peatland in the lower class requires management to reduce subsidence[8]; for example, (1) by using the peatland as paddy fields on a large scale, especially for High moor peatland, (2) by improving the management of the groundwater level in the use of upland fields, (3) by avoiding the mixing of top-dressed soil with peat layer associated with deep plowing of upland fields, (4) by maintaining an adequate thickness of the top-dressed soil layer in arable land to prevent the decomposition of the peat layer.

Conclusion

In the Ishikari peatland in northern Japan, the recent average rate of subsidence of arable peatland was estimated to be 1 cm/y for paddy fields and 3 cm/y for upland fields. Comparison of the topography and soils of a windbreak forest and marshland, revealed that the height difference caused by subsidence exceeded 3 m and that about 80% of the organic carbon in the peat layer had been decomposed due to the change of land use 40 years previously.

We evaluated the sustainability of arable peatland based on forecasting data of subsidence, and we compiled an evaluation map of the Ishikari peatland using the GIS. Soil type, period of land development, present land use and thickness of top-dressed soil were selected as main factors for the evaluation, and scores of elements of each factor were determined. According to the sum of these scores, sustainability of arable peatland was divided into 3 classes; high, moderate and low. An evaluation map of arable peatland in terms of subsidence was compiled using these classes.

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