博士（工 学） ロフィク イクバル

学位論文題名

THE CONSERVATION OF SAROBETSU MIRE: Restoration of Water Chemistry Regime and Its Relevance to Vegetation Succession

（サロベツ湿原の環境保全－水質管理と植生遷移－）

学位論文内容の要旨

Land reclamation such as deforestation, agriculture, drainage, urbanization and residential development has large impacts on the ecology of the surrounding ecosystems. These include the changes of animal and plant communities, as well as the changes in hydrology and hydrochemical regimes. Sarobetsu Mire, a raised bog in northern Hokkaido, is a case in point. Its ecosystem is gradually losing its natural state because of human perturbations at the surrounding area, causing the water level to decrease and threatening a change in the entire mire ecosystem. Some early signs for the change were a reduction of water levels and an invasion of an exotic plant, *Sasa spp.*, at the western part of the mire.

A study in this area was carried out to investigate the changes in water chemistry regimes and the composition of the vegetation along east-west direction which corresponds to the degradation gradient. Surface and subsurface (0.5, 1.0, 1.5, and 2 m depths) water chemistry was sampled 36 times during 1993–2003 at 5 representative points: point E (natural area with *Sphagnum* as the main vegetal cover), point W (boundary between the natural and degraded area), point W' (area installed with vinyl sheet), point WW (area where *Sasa* thrives (Leaf Area Index (LAI) = 1.8)), and point NC (area with naturally formed ditches where the LAI is 1.3 and no *Sphagnum* is present). The composition of the vegetations was studied using Braun-Blanquet coverage method.

Using Analysis of Variance (ANOVA) to calculate the variation of all water samples, it was revealed that "sampling point" (i.e., locations along the degradation gradient) accounted for most of the variation in water chemistry. It accounted for 30–80% of the total variation in pH, electrical conductivity, ammonia, dissolved nitrogen, sodium, potassium, calcium, magnesium, alkalinity, silicate, and dissolved organic carbon concentration. "Year" accounted for more variation in nitrate, nitrite, chloride, and sulfate than points did, while the variation in DRP and DP concentrations were not based on any of the calculated variables. The errors for these two parameters were 56% and 68% respectively, perhaps due to their low concentrations, thus would be easily affected by any changes on the mire surface. For the surface water chemistry, however, the degradation status did not account for the variations, except for pH, where "sampling point" accounted for 26% of the total variation. For other parameters (EC, NH_4, NO_2, DN, DRP, all base cations (Na^+, K^+, Ca^{2+}, and Mg^{2+}), alkalinity, SiO_2, and DOC), the "sampling point" accounted for the variations only when associated with the yearly differences. The composition of the plants community also revealed the differences along the degradation gradient, which only point E to be found ombrotrophic. Even at the boundary between the *Sphagnum* area and *Sasa*-invaded area where the water chemistry is relatively unchanged, we already can find *Moliniopsis japonica* and *Trientalis europaea var. arctica*, which are considered as minerotrophic plants. Point W' is found to be the richest area and host both ombrotrophic and minerotrophic plants, such as *Rubus chamaemorus-Sphagnum papillosum* communities.

These results indicate that the low and unstable water levels at the degraded part of the mire affect the

water chemistry regimes by the possibility of inflows from the surrounding areas, accumulation of mineral and nutrients in the smaller amount of water, evaporative effect and also the leaching of decomposed peat soils. The latest also caused the formation of gully systems due to the fundamental change in the hydrology of the peat mass. The decline of water levels also closely related to the overall hydrological function which governs the nutrient cycle in the mire. The availability of nutrient for plants communities – which should be remain low in bog ecosystem – was greatly disturbed due to enhancement of mineralization process such as microbial activities to convert organic compounds into inorganic nutrient.

The above deductions enlighten the importance of the restoration of water chemistry and the hydrological regime to its natural condition to maintain the original vegetation of the mire community. This restoration is approached by installation of dams along the gully systems. It is found that the water chemistry restoration at near surface could be achieved, since the rainwater itself has the properties desirable for raised bog, i.e. low pH and EC values, and low mineral and nutrient contents. Further effect of the dams is the increment of water level which also desirable to restore the water chemistry, since the increased water level led to the reduction of dissolved oxygen in water hence hindering mineralization by microbial activities. However, the restoration of ground water chemistry seemed to need longer period. Prolonged inundation and/or soil saturation is further proved important to allow deeper penetration – thus restoring water chemistry of the ground waters –, since there is obvious difference between newly installed dam with the longer one on the extent of water chemistry restoration toward depth. Considering the possibilities of the influence of mineral-rich groundwater from surrounding areas, the inundation is also important to hinder the upward flow that can happen during dry periods. The balance between prolonged inundation and upward movement of ground water, or the capability of the inundated water to hinder the groundwater to reach the surface, might also be affected by the presence of low-permeability layer which acts as a 'boundary layer' as a result of compaction of the soil by continuous alteration between wet and dry conditions at the channel bed.

While the water levels and the water chemistry were reinstated, the complete re-establishment of the hydrological regime similar to natural bog ecosystem is yet to be achieved. The fluctuation of water levels is still high, which seemed affecting the biogeochemical cycle and determining the plants communities conserved therein. The differences in DOC concentrations between those at the natural and the restoration site for example, might be owing to the difference in the fluctuations of water level as well as the different species of *Sphagnum*. The high DOC concentration at the preserved area is caused by the ability of *Sphagnum* species that living at stagnant waters, such as *Sphagnum papillosum*, to elude organic contents from the soil. This *Sphagnum* species is not found at the restoration site.

Considering the succession of plants species, canonical correspondence analysis revealed that even though the dams succeeded to restore the surface water chemistry, they did not exactly revert back toward the natural bog communities as comprised at the preserved area. At the restoration site, the water availability showed stronger effect in the vegetation succession, and the fluctuation of water levels seemed to determine the vascular plant species. The microtopography of the soil surface, i.e. hollow - hummock gradient, is considered to be the main reason for this difference, which further hinder the restoration of the whole hydrological regimes. Therefore, the use of water level and the variation of water levels as co-variables of pore water chemistry allowed the distinction of specific response of plant communities to the environment variables.

Nevertheless, the restoration of water chemistry regimes maintains a well deserved place of importance for the conservation of raised mire ecosystems. The poor-nutrient status will enhance the growth of blanket bog bryophytes, which will further develop this peat-forming habitat. The stable and high water level is the condition that will support this development. The conservation of Sarobetsu Mire in the future needs to consider not only the restoration of water chemistry but also other environmental aspects, such as topographical and morphological data, and the status of hydrological regime.

学位論文審査の要旨

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(サロベツ湿原の環境保全－水質管理と植生遷移－)

近年、高層湿原保全の研究が盛んに行われるようになった。しかし、その多くは人間活動の結果変貌した湿原の植生や直接的原因となった農業活動の影響に限られ、湿原変貌の実態やそのメカニズムの解明、さらにはその復元方法についての研究など、今後の進展が待たれている状況にある。

本論文は、このような現状にある湿原保全の研究について、詳細な現地調査や現地実験を基礎に、変貌の実態を化学的そして水理学的な視点から研究し、湿原の植生変化の要因そして復元方法の原則を明らかにすることができた。これらは今後の湿原研究の基礎的資料として、さらに湿原再生事業の一手法として活用されることが期待される。

対象とした高層湿原は、第二次世界大戦後の農地開発の結果、植生が大きく変化した北海道の北部豊富町に位置するサロベツ湿原環境省特別保護区である。農業を中心とした排水は地下水位を大幅に下げ、農業は一大産業に育ったが、一方で湿原には笹が侵入し自然植生が破壊される結果となった。著者は、地下水位の低下と植生の関係を地下水質成分の濃度分布とその構成から解析し、さらに両者の因果関係から湿原から流出する湿地溝にダムの構築することに大きな効果のあるものと判断し、降水の湛水による植生の復元を試みた。

第一章では研究目標と論文構成を、第二章では湿原研究についての既往研究をまとめた。すなわち湿原における土地利用の変化の湿原環境に及ぼす影響を、水理的、水質学的そして植生遷移の視点からまとめ、湿地溝ダムの植生復元効果を諸外国の既往研究をもとに整理した。第３章では、著者の調査データを含めた１９９３年以来の詳細なデータをもとに、サロベツ湿原対象域の水位低下と水質変化の実態を明らかにした。またPiper　Diagramや多変量解析（主成分分析、ANOVA）によって、地下水質は湿原の東部から西部へと貧栄養性から鉱物質栄養性に変化し、また多くの水質成分において調査地点の全変動への寄与が

５０－６０％に達することを明らかにし、本湿原が農業活動の影響によって高層湿原から低層湿原の植生に変化していることを確認した。第４章では、第３章のデータをもとに、湿地溝ダムによる改変された湿原の回復の理論的根拠を明らかにし、ダム建設による効果を地下水レベル、水質、植生の現場観察によって確認した。また主成分分析、CCA解析によって、これらが相互に関係していることを明らかにした。第５章では湿地溝ダムによる降水貯水の理論的考察を行った。特に複数のダム貯水の実態を比較し、経時的に清澄な降水の貯水能力が高まるとした。極めて注目される湿地溝ダムの有効性の指摘である。第６章では本研究で得られた新しい知見をまとめ、人為活動による湿原環境の劣化の原因をまとめ、今後の保全対策を湿地溝ダムの有効性を中心にまとめている。

これを要するに著者は，笹侵入など環境変貌の著しいサロベツ湿原に関し詳細な地下水質ならびに植生データの収集を行い、その多変量解析・CCA解析を試み，同湿原の低層湿原化さらには湿原荒廃を確認するとともに，湿地溝ダムによる湿原環境復元方法を初めて提案しその有効性を明らかにした．これらの成果は環境工学，湿原保全工学に資するところが大であり，北海道大学博士（工学）の学位を授与される資格があるものと認める．