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研究課題名（和文）Mechanisms leading to the development of alternative stable states in peatland vegetation during secondary succession after disturbance by volcanic ash

研究課題名（英文）Mechanisms leading to the development of alternative stable states in peatland vegetation during secondary succession after disturbance by volcanic ash

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研究成果の概要（和文）：湿原植生が火山活動による攪乱を受けた時、どのように応答するか、中期的な動態については野外実験、短期的な動態については室内実験実験において解明した。野外実験では、火山灰降下による攪乱を再現する実験処理を与えた後、5年または8年経ったところ、同様の処理におけるヤチヤナギの対照的な反応が確認され、代替安定状況が発達したが、20年後はヤチヤナギの被度が下がり、代替安定状況が長期的に維持されないことが明かになった。一方、室内実験においては、火山灰堆積と酸性雨による影響を調べた。強酸性（pH2）の降水のみを与えたら、ミズゴケの成長妨げられたが、酸性（pH4）の降水や火山灰を与えた場合、回復が早かった。

研究成果の学術的意義や社会的意義
活火山が広く分布する日本において、火山灰降下や火山性酸性雨が生態系に及ぼす影響を解明することは、基礎科学だけでなく、防災・減災の観点からも重要である。本研究では、降下火山灰や火山性酸性雨の湿原植生への影響を野外実験と室内実験において解明した。広域的に堆積する数センチ程度の火山灰による植生の変化は、数年で元に戻ることが確認できた。火山が排出するガスによって、酸性雨が発生することがあるが、ミズゴケへの悪影響は、自然界でめったに起きない強酸性の場合に限って確認された。広域に降下する火山灰の影響が一時的で、種組成や種の被度の変化による遷移が起こり得るが、元の状態が回復することが予想される。

研究成果の概要（英文）：Medium term and short term effects of tephra deposition on mire vegetation were investigated in a field experiment and laboratory experiments. In the field experiment, treatments mimicking tephra deposition led to divergent responses of the dwarf shrub Myrica gale after five to eight years, indicating the development of alternative stable states. After 20 years, the cover of M. gale had declined, showing that the alternative state with high cover was not maintained. In the laboratory experiments, effects of acid precipitation and tephra deposition were tested. Strongly acid precipitation (pH2) supressed Sphagnum growth, whereas acid precipitation (pH4) and tephra deposition allowed fast recovery. Interactions between tephra particles and acid in the solution applied as precipitation apparently played a role in reducing the detrimental effect of the acid on Sphagnum growth.

研究分野：Landscape ecology

キーワード：vegetation　alternat. stable states　disturbance　volcanism　resilience

１．研究開始当初の背景

Understanding the consequences of geological events such as volcanic eruptions on biological communities and ecosystems is an important task not only from a fundamental science perspective, but also from the viewpoint of disaster risk reduction. In addition, clarifying the mechanisms that lead to changes in community composition and/or alterations of ecosystem functioning is a core task for ecological research. At the outset of the current project, some evidence was available that moderate ashfall can induce changes in species composition and abundance of species in mire communities. Hypotheses concerning possible mechanisms included changes in nutrient availability and biotic interactions between vascular plants and microbial symbionts.

２．研究の目的

The current project was designed to elucidate medium term and short term effects of tephra deposition on mire vegetation in a field experiment and laboratory experiments. The field experiment had been started in 2000 at Sarobetsu Mire in northern Hokkaido. Treatments mimicking tephra deposition of different intensity had led to divergent responses of the dwarf shrub *Myrica gale* after five to eight years, indicating the development of alternative stable states. In the current project, vegetation and shallow groundwater chemistry were investigated 20 years after the experimental disturbance in order to test the hypothesis that positive feedback between raised *Myrica* cover and nutrient availability - mediated through negative effects on *Sphagnum* moss cover - can stabilize the state with dominant *Myrica* for over a decade.

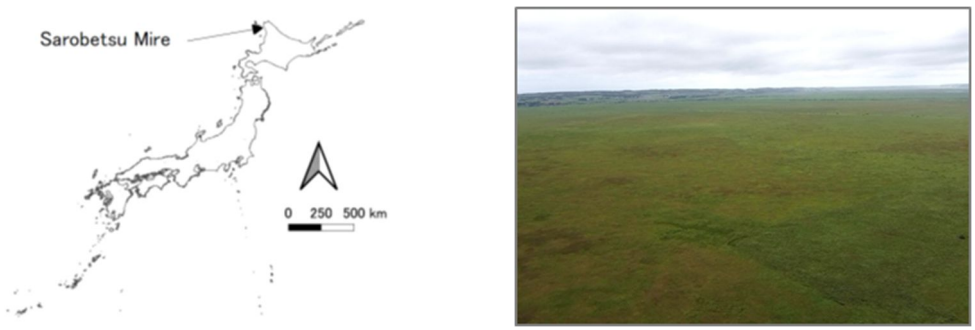

Fig. 1 Location of Sarobetsu Mire in northern Hokkaido and drone image of the site of the field experiment. The experimental site is visible in the centre foreground (mesh-like structure).

In the laboratory experiments, effects of acid precipitation and tephra deposition on the growth of Sphagnum moss were tested. Strongly acid precipitation (pH2) and acid precipitation (pH4) were combined with 0.5 cm to 1.5 cm of tephra to investigate the effects of acids and mineral layers alone and in combination.

Parallel to the experimental work, a review of the literature on tephra deposition in the Japanese Archipelago was carried out, including publications in English and other European languages as well as in Japanese.

３．研究の方法

The field study utilized 60 experimental plots of 1.4 m x 1.4 m established in a 6 x 10 grid pattern in 2000 at Sarobetsu Mire in northern Hokkaido (Fig. 1). The plots are located in the central part of a *Sphagnum*-dominated area. Phytosociologically, the community is characterized by *Sphagnum papillosum*/*S. magellanicum* forming a lawn in which vascular plants grow in patches. *Carex middendorffii* is the most regularly occurring vascular plant, followed by *Hosta sieboldii* and *Hemerocallis middendorffii*.

Natural tephra from the AD 1739 eruption of Tarumae volcano in southern Hokkaido was applied to form layers of 1 cm, 3 cm and 6 cm in September 2000. Fine grained glass powder and coarser glass grains derived from recycled bottles were applied to a thickness of 3 cm in order to compare material with different grain sizes. The treatment with 3 cm of natural tephra was repeated in May 2001 to test the effect of the timing of the disturbance event.

Fig.2 Drone image of the experimental plots and spatial arrangement of the seven experimental treatments in the field experiment at Sarobetsu Mire.

Vegetation data were recorded in a regular 20 cm x 20 cm grid for the central one square meter of each plot giving a total of 1500 mesh cells. All plant species were recorded, and their cover was estimated using the Schmidt-Londo scale. Surface peat pore water was sampled from ca. 20 cm depth at the center of each plot using 10 cm soil moisture samplers and 50 ml syringes for creating a vacuum to collect 100 ml - 200 ml of pore water. Physical and chemical water quality indicators were measured using the following instruments: pH (Horiba D-51 pH meter), Na, K, Ca, Mg, Al, Fe, Si, P, S (Thermo Scientific iCAP 7000 Series ICP-OES), TOC and TN (Shimadzu TOC-L).

In the laboratory experiment, Sphagnum moss (Sphagnum palustre) purchased from specialized suppliers of gardening materials was placed in 250 ml round plastic containers to create Sphganum stands with conditions similar to the Sphagnum lawn communities in mires of Hokkaido. Ca. 10 shoots were placed in each container. In pre-trials, suitable growing conditions were tested as well as different materials to be used as tephra substitutes and solutions for mimicking volcanically induced acid precipitation. The main experiment testing 20 g of tephra substitute derived from the Shirasu volcanic deposits of the Aira caldera eruption in Kagoshima Prefecture, diluted sulphuric acid with pH 2 and pH 4 either on their own or in combination with the tephra substitute.

Fig. 3 Mesocosms (250 ml plastic containers). Three levels of acid precipitation (distilled water, sulfuric acid pH 4, sulfuric acid pH 2) were com bined with two levels of tephra deposition (20 g versus none).

4．研究成果

The cover of M. gale had declined 20 years after the experimental disturbance and 12 years after the previous vegetation survey, showing that the alternative state with

high Myrica cover was not fully stable, although the dwarf shrub was still more abundant within several plots than it had been prior to the experimental disturbance (Fig 4).

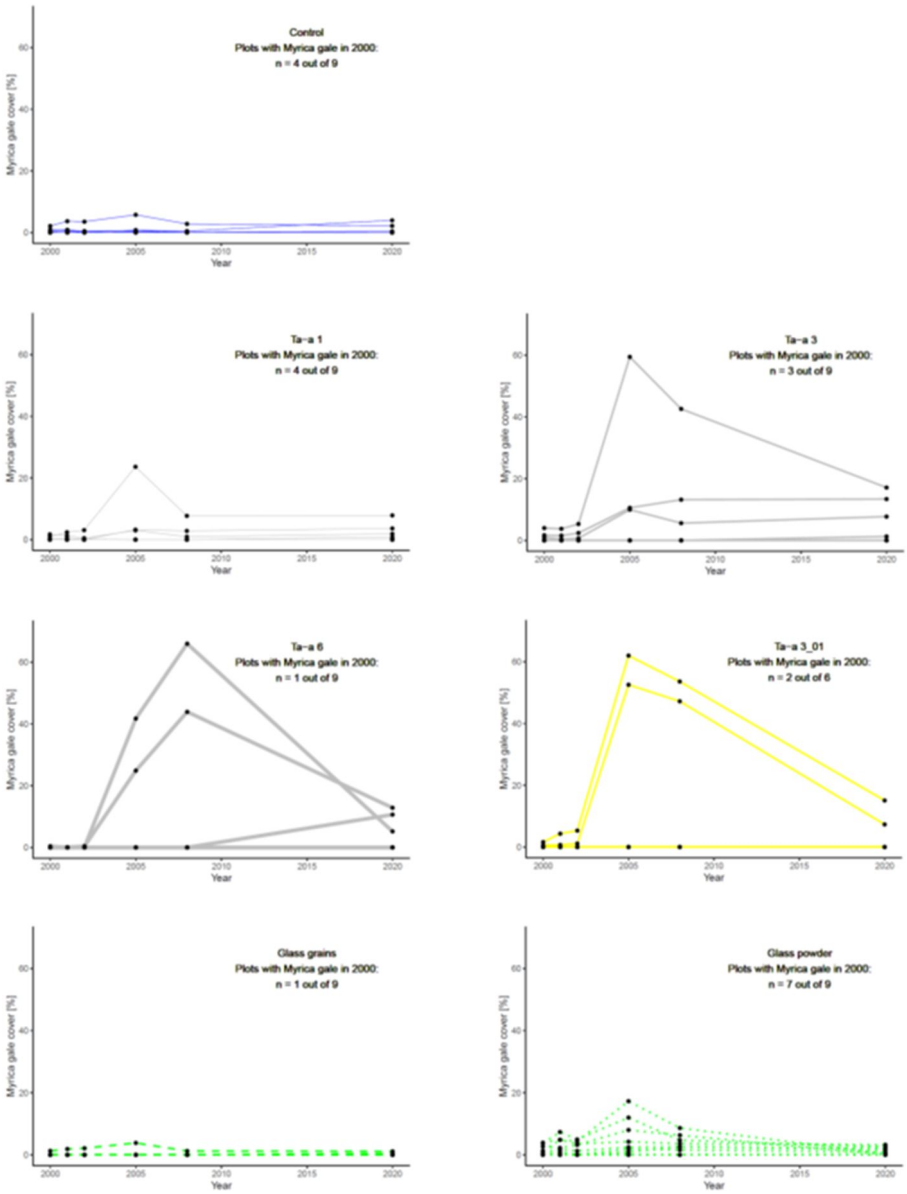

Fig. 4 Changes in *Myrica gale* cover at plot level, shown separately for each treatment.

The changes in *Myrica* cover per plot over time are shown separately for the seven treatments in Fig. 4. The increase in cover in 2005 occurred simultaneously in several plots, irrespective of the treatment, suggesting some general driver that may have favoured the increase, but only treatments with three or six centimetres of natural tephra showed five- to sixfold increases. The hypothesis that such pronounced shifts may induce positive feedback that can stabilize bimodal frequency distributions of Myrica gale cover, possibly with consequences for nutrient cycling and carbon sequestration was not supported by the vegetation survey data which showed clear trends towards reduction in cover or constancy at comparatively low cover levels.

One hypothesis for the increase in *Myrica* cover in 2005/2008 included a mechanism via enhanced nutrient availability, possibly in connection with changes in the abundance or activity of nitrogen-fixing actinomycetes. To test whether the higher *Myrica* cover coincided with higher concentrations of nitrogen in leaves, leaf tissue from all plots in which Myrica was present was analyzed for carbon and nitrogen content. Leaf nitrogen stable isotope ratios were determined for ten representative samples along the *Myrica* cover gradient. Neither the nitrogen content nor the nitrogen stable isotope ratios

showed a link to Myrica gale general cover. This suggests that nitrogen allocation to leaf tissues was the same irrespective of *Myrica* abundance.

In the laboratory experiment, strongly acid precipitation (pH2) supressed *Sphagnum* growth, whereas acid precipitation (pH4) and tephra deposition allowed fast recovery (Fig. 5). Interactions between tephra particles and acid in the solution applied as precipitation apparently played a role in reducing the detrimental effect of the acid on *Sphagnum* growth.

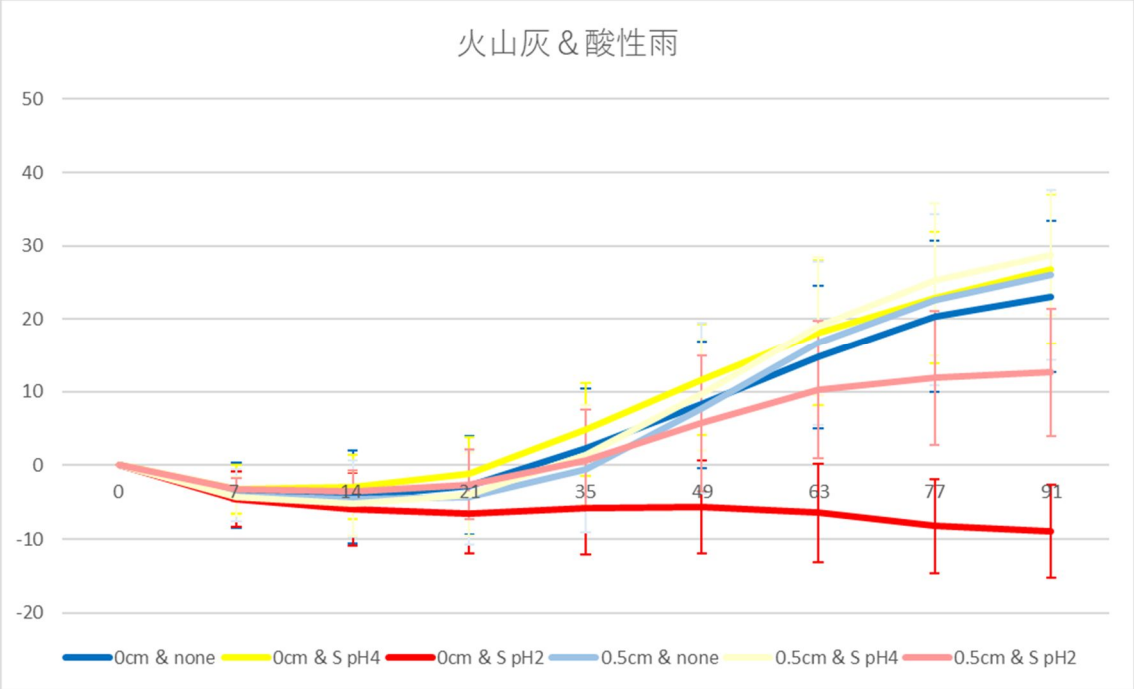

Fig. 5 Changes in height of the capitulum of Sphagnum plants in mesocosms trwated with

The findings gained in this project support the conclusion that mire vegetation shows resilience in response to different aspects of disturbance related to volcanic activity. Because no biomarkers for measuring the relative contribution of actinorhizal nitrogen to the growth of *Myrica gale* have been identified, testing whether allocation of nitrogen to different plant organs may be affected, remains a task for further work.

５．主な発表論文等

〔雑誌論文〕　計0件

〔学会発表〕　計0件

〔図書〕　計0件

〔産業財産権〕

〔その他〕

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６．研究組織

	氏名 （ローマ字氏名） （研究者番号）	所属研究機関・部局・職 （機関番号）	備考

７．科研費を使用して開催した国際研究集会

〔国際研究集会〕　計0件

８．本研究に関連して実施した国際共同研究の実施状況

共同研究相手国	相手方研究機関