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Deterrent Effect of Rosin and Wood Tar against Barking by the Gray-sided Vole (*Clethrionomys rufocanus bedfordiae*)

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The gray-sided vole (*Clethrionomys rufocanus bedfordiae* Thomas) is a small wild rodent widely distributed in Hokkaido, northern Japan. Floors of forestry plantations with thick herbage provide gray-sided voles with suitable habitats. The voles eat bark in winter, and because of this, severe damage can occur in many plantations. Deterrent effects on gray-sided voles of rosin and 3 wood tars were evaluated by two-choice tests in the field. These materials were selected because they were promising and economical deterrents. In the test for each material, disks were produced from trunks of Japanese larch, and used as carriers. Pairs of carriers (a material-treated carrier and a control carrier) were fed to gray-sided voles for 24 h, and values of the eaten area of bark were compared between treated carriers and controls. Every material decreased the extent of barking. The treated carriers were significantly less eaten compared to the controls for all the materials ($p < 0.01$ or 0.05). Deterrent effects of three fractions (neutral, phenol, and strong acid fractions) made from wood tar were also evaluated. Every fraction prevented gray-sided voles from barking. The treated carriers were significantly less eaten compared to the controls for all the fractions ($p < 0.05$). The neutral fraction has showed an especially strong deterrent effect; thus this fraction is most promising for future use.

Key words: deterrent effect, forestry damage, rosin, the gray-sided vole *Clethrionomys rufocanus bedfordiae*, wood tar

The gray-sided vole (*Clethrionomys rufocanus bedfordiae* Thomas) is a small wild rodent widely distributed throughout Hokkaido. It inhabits open areas covered with grasses. It also inhabits forestry plantations where thick herbage, such as bamboo grass (*Sasa* spp.), covers the floors (Higuchi, 1970; Kaneko *et al.*, 1998). The plantations provide gray-sided voles with suitable habitats. The herbage is the main food source for them and also protects them against predators or unfavorable weather conditions (Kaneko *et al.*, 1998).

Gray-sided voles mainly feed on buds, leaves, and stalks of herbage such as bamboo grass and sedge (*Carex* spp.), and they also eat nuts in autumn and bark in winter (Maeda *et al.*, 1984; Kaneko *et al.*, 1998). As a result, in winter when the vole population density is high, serious damage to trees can occur in forestry plantations in Hokkaido (Kaneko *et al.*, 1998).

From the 1950s to the 1960s, Japanese larches (*Larix kaempferi* Carr.) were planted to a large extent because their growth was excellent compared to other conifer species, such as *Abies sachalinensis* Masters and *Picea glehnii* Masters, in Hokkaido. However, the larches had very weak resistance to gray-sided voles. Severe damage from them has occurred in larch plantations and forestry managers have suffered serious economical losses.

To prevent damage from gray-sided voles, rodenticide containing zinc phosphate has been scattered on forestry plantations every autumn in Hokkaido (Kaneko *et al.*, 1998). This method was established in the 1950s and was suitable for large-area and clear-cutting plantations which were common in those days (Maeda, 1984; Nakatsu, 1990a).

After the 1970s, however, with different forestry management plans, small plantations in natural forests have been increasing in the national forests of Hokkaido (Maeda, 1984; Nakatsu, 1990a). The conventional prevention method using rodenticide is unsuitable for the small plantations (Maeda, 1984; Nakatsu, 1990a). Moreover, field mice (*Apodemus* spp.) entering from the surrounding natural forests into the small plantations have been increasing, with the increased risk of their ingesting rodenticide (Nakatsu and Kawaji, 1992; Nakatsu *et al.*, 1993). Thus, the prevention method using rodenticide needs to be improved, and alternative methods, which protect animals not targeted, should be considered.

Use of deterrents is considered to be an effective solution to this problem. However, there are few plantations in Hokkaido which have been practicing prevention by using deterrents. Moreover, there have been few studies done on the use of deterrents until now (Higuchi and Taniguchi, 1989; Nakatsu, 1990b; Nakata and Unno, 1996), and none have resulted in practical guidelines for use. Therefore, it is necessary to start basic research on the use of deterrents.

Deterrents against gray-sided voles must be effective and economical. From this point of view, rosin and wood tar are attractive deterrent candidates. Rosin is a component of resin. Previous studies have indicated that resin (or ether extracts) in bark is related to the resistive properties of *Larix* species and hybrids to the gray-sided vole (Inukai and Haga, 1952; Yanagisawa and Kawanishi, 1955; Nishiguchi *et al.*, 1977; Chiba *et al.*, 1991; Ogawa *et al.*, 1992; Hayashi *et al.*, 1998). Therefore, we expected that by spraying rosin on the surfaces of trees, we would render them unpalatable to the voles. Also, wood tar is one of the by-products of charcoal manufacturing in Hokkaido. In Finland, Löyttyniemi *et al.* (1992) reported that wood tar made from Scots pine (*Pinus sylvestris* L.) prevented moose (*Alces alces* L.) damage to young pine stands. Therefore, we also expected that wood tar might be a deterrent for gray-sided voles.

Rosin is generally considered to be a sizing agent and is used extensively in the paper industry, and wood tar is an

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industrial waste in Hokkaido. Therefore the cost of using them is very low, and economically they are attractive candidates as deterrents for gray-sided voles.

Based on these facts, the present study was designed to evaluate the deterrent effects of rosin and 3 wood tars against barking by gray-sided voles. Evaluation was performed by two-choice tests in the field.

Experimental Field, Materials, and Methods

1 Experimental field

A 1.35 ha (190 × 71 m) shelter belt of the National Forest, south of Tobetsu Town, western Hokkaido (141°30′N, 43°10′E) was chosen as the experimental field. This belt consists of *Fraxinus mandshurica* Ruprecht var. *japonica* Maxim. *Populus maximowiczii* Henry, and *Aluns japonica* Steud. The floor of this belt is covered with bamboo grass (*Sasa* spp.), and it is a favorable habitat for gray-sided voles. The continuous snow cover period at this belt is usually from the end of November to the beginning of April. The snow depth reaches about 100 cm from the beginning of January to mid-March, with a maximum depth of about 120 cm.

2 Experimental devices

The experiment was planned in the continuous snow cover period when gray-sided voles eat bark. The voles are active in the air space between the snow cover and the ground. To supply feed to the voles, we used an experimental device that consists of a box and a stand (Fig. 1). The stand is taken in and out through the box standing in the snow, and feed from the stand is given to the voles that are active in the air space.

A box consisted of a 70 × 30 × 30 cm body, a 30 × 30 cm top lid and four 15 cm legs. The box's body and the lid were made of plywood, and the legs were made of square rods. A stand consisted of a 25 × 25 cm body with four 1 cm walls and a 60 cm handle. The stand's body was made from plywood, and the handle was made from a square rod. In total 10 devices were used in the study.

3 Installation of experimental devices

The snow was removed from an area corresponding to the size of a box, and then the legs of the box were inserted in the ground. The box was installed with about 3 cm of space between the ground and the bottom of the box's body, through which gray-sided voles could enter and exit (Fig. 2). Peanuts and branches of Japanese larch were put on a stand, and the stand was set into the box. Finally, the top lid was closed and the device was buried in the snow. The 10 devices were positioned at 20–30 m intervals in the field on December 1, 1998.

4 Experiment 1 (two-choice tests on rosin)

1) Test material

Rosin manufactured from *Pinus massoniana* Lamb. was tested as a deterrent to gray-sided voles in this experiment. The rosin was dissolved in 95% ethanol to prepare a test solution of 40% (w/v).

2) Carriers

Disks about 3–7 cm thick and 4–9 cm diameter were produced from trunks of Japanese larch, and used as carriers in two-choice tests. The larches used were about 10 years old. They were felled in the Kyushu University Forest, Ashoro Town, eastern Hokkaido on October 27, 1998 and March 1, 1999. They had been stored at − 10°C in a freezer until the tests.

3) Procedure

The experiment proceeded in three steps.

(1) Surveys of use of each device by gray-sided voles

The surveys were carried out at intervals of several days. Peanuts and branches of Japanese larch were supplied on the stand in each device several days before each survey. The use of each device by gray-sided voles was surveyed by checking the excrement left on the stand and the decrease

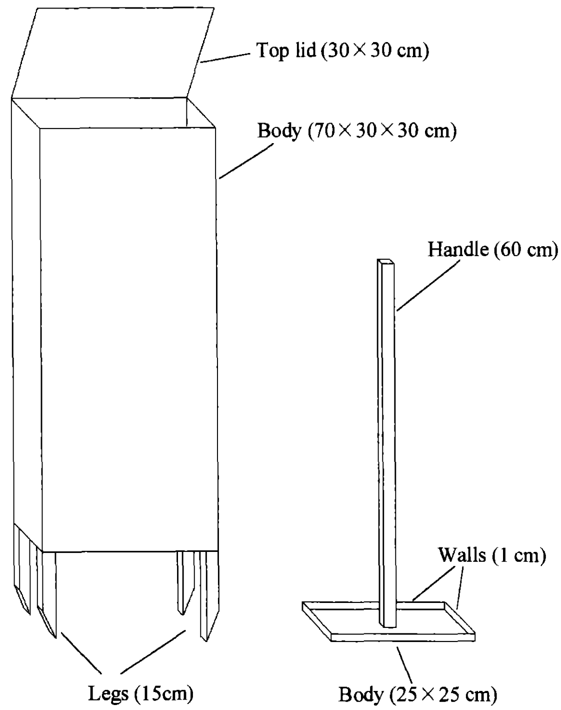

Fig. 1 An illustration of the experimental device. Note: The experimental device consists of a box (left) and a stand (right) which were made of plywood and square rods.

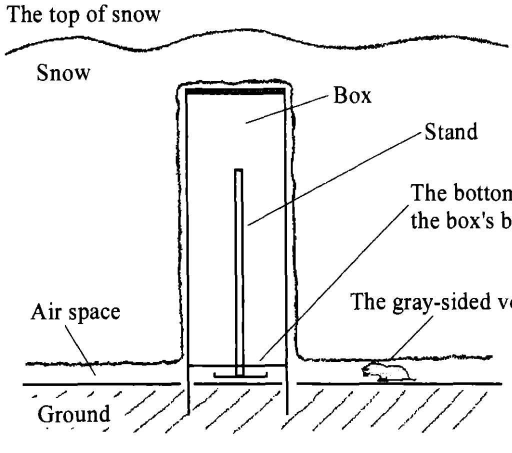

Fig. 2 An illustration of installation of an experimental device. Note: Ten devices were positioned at intervals of 20–30 m in the field on December 1, 1998.

of the feed supplied.

The voles consistently used 9 of 10 devices. Therefore, two-choice tests were carried out using these 9 devices.

(2) Measurement of the area of bark eaten by gray-sided voles per 24 h in each device

Two or 3 carriers were put into each device, and were fed to gray-sided voles for 24 h. After all carriers were collected, the eaten area of each carrier's bark was measured, and a total eaten area in each device was calculated. This measurement was repeated 2 to 3 times. The mean value of total eaten areas was calculated as the eaten area per 24 h in each device.

(3) Two-choice tests

Two-choice tests for 2 application rates (0.0125 and 0.025 mL/cm^2) were designed. In terms of mass, the rosin was applied at a rate of 5 or 10 mg/cm^2, respectively.

In the test of each rate, a pair of carriers was prepared from the contiguous part of a larch's trunk for a device. The bark area of each carrier of the pair was 1.5 times greater than the eaten area per 24 h measured previously (see Section **4.3)(2)**). The test solution was applied to the bark of one of the pair (material-treated carrier) with a brush, and the solvent (95% ethanol) was applied to that of the other (control carrier) at the same rate. The pair air-dried until the solvent evaporated completely, and was put into the device. The test was conducted for 24 h. After the pair was collected, the eaten area of each carrier's bark was measured. The test was carried out one by one in 8 devices.

In each device, the 2 rates were tested in random order from February 23 to March 5, 1999. An interval ≧ 1 day was taken between the tests.

5 Experiment 2 (two-choice tests on 3 wood tars)

1) Test materials

Wood tars manufactured from 3 species, an alder (*Aluns maximowiczii* Callier), Japanese larch (*Larix kaempferi* Carr.), and Japanese white birch (*Betula platyphylla* Sukatchev var. *japonica* Hara) were tested as deterrents to gray-sided voles in this experiment. The wood tars from the alder and the birch were manufactured by dry-distilling methods. The wood tar from the larch was a by-product of a charcoal manufacturing process. Wood vinegar manufactured from the alder was also tested to compare the deterrent effect with those of the wood tars. Each wood tar was dissolved in 95% ethanol to prepare a test solution of 40% (w/v). The wood vinegar, just as it was, was used as a test solution.

2) Carriers and procedure

Carriers were prepared as described in Section **4.2)**. The experiment proceeded in three steps. The first two steps were carried out as described in Section **4.3)(1)** and **4.3)(2)**, respectively. The third step was carried out as described in **4.3)(3)** except the following. A two-choice test between each material and control was designed. In the test of each wood tar, the test solution was applied to carriers at the rate of 0.0125 mL/cm^2, and the solvent (95% ethanol) was applied at the same rate. In terms of mass, each wood tar was applied at the rate of 5 mg/cm^2. In the test of the wood vinegar, the test solution was applied to carriers at the rate of 0.025 mL/cm^2, and distilled water was applied at the same rate.

The test for each material was carried out one by one in 8 devices. In each device, the 4 materials were tested in random order from March 11 to 20, 1999. An interval ≧ 1 day was taken between the tests.

6 Experiment 3 (two-choice tests on fractions from wood tar)

1) Test materials

The wood tar from the alder was dissolved in diethyl ether, and the ether soluble part was separated from the residue. The soluble part was further fractionated into neutral, phenol, and strong acid fractions (see Fig. 3). After the solvent had been removed using a rotary evaporator, each fraction was dissolved in 95% ethanol to prepare a test solution of 40% (w/v).

2) Carriers and procedure

Carriers were prepared as described in Section **4.2)**. This experiment followed the second experiment without a break. The data of the bark area eaten by gray-sided voles per 24 h in each device, which were measured in Section **5.2)**, were also used in this experiment.

A two-choice test between each fraction and control was designed and performed as in the tests of the wood tars (see Section **5.2)**). The test for each fraction was carried out one by one in 7 devices. In each device, the 3 fractions were tested in random order from March 19 to 25, 1999. An interval ≧

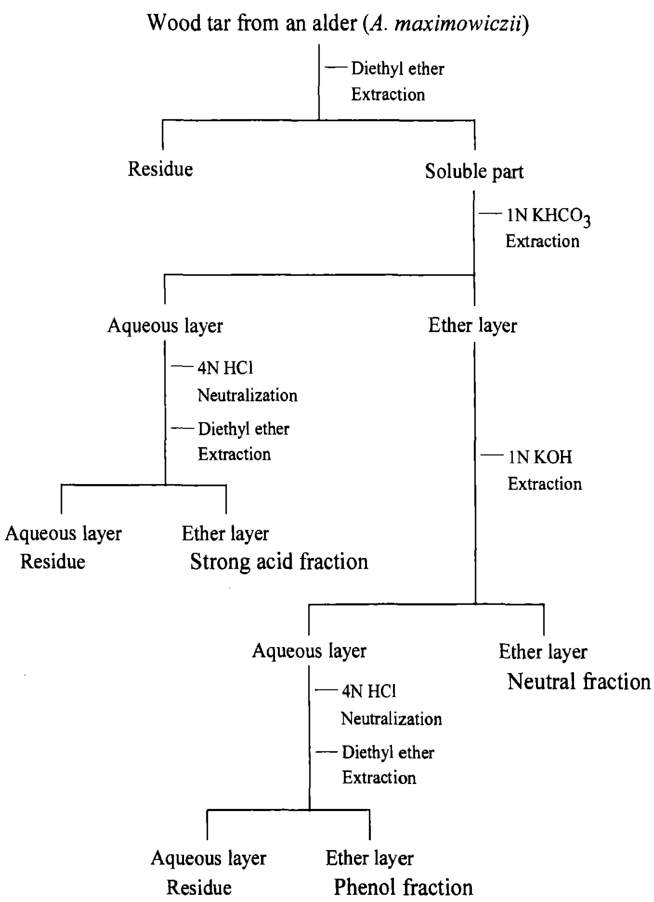

Fig. 3 A flow sheet of preparation of fractions of wood tar from an alder (*A. maximowiczii*).

1 day was taken between the tests.

7 Analyses

For each material and application rate tested, values of the eaten area of bark were compared between material-treated carriers and controls with the Wilcoxon signed-ranks test. Also, the relative preference of the treated carrier to the control in each device was expressed by a preference index (= the eaten area of treated carrier/that of control) following the model of Reichardt *et al.* (1984).

Result

1 Experiment 1 (two-choice tests on rosin)

The material-treated carriers were significantly less eaten compared to the controls for both application rates of the rosin ($p < 0.01$, Table 1a). Also, the mean value of the eaten area for the rate of 10 mg/cm^2 was about half as much as that for the rate of 5 mg/cm^2 (Table 1a).

The preference indices varied widely among the devices used in both application rates (Fig. 4a). The indices for the rate of 10 mg/cm^2 tended to be smaller than those for 5 mg/cm^2.

2 Experiment 2 (two-choice tests on 3 wood tars)

The material-treated carriers were significantly less eaten compared to the controls for all the wood tars (alder and larch, $p < 0.01$; birch, $p < 0.05$, Table 1b). Considering the wood vinegar, there was no significant difference in the eaten area between the treated carriers and the controls ($p > 0.05$, Table 1b).

The preference indices varied widely among the devices used for all materials (Fig. 4b, c). The indices for the tars from the alder and the larch tended to be small compared to that from the birch. Their distribution was similar to that for the 10 mg/cm^2 application rate of the rosin (Fig. 4a).

3 Experiment 3 (two-choice tests on fractions from wood tar)

The material-treated carriers were significantly less eaten compared to the controls for all the fractions ($p < 0.05$, Table 1c). The preference indices for the neutral fraction showed especially small values (Fig. 4d). The variation of the indices was larger for the other fractions.

Discussion

Rosin mainly contains resin acids, and also contains small amounts of neutrals, such as terpenes, stilbenes, sterol, fatty alcohols, and hydrocarbons (Teratani, 1985). Resin acids exude and solidify on surfaces of traumatized parts of wood tissue to prevent fungous infections (Harborne and Baxter, 1993; Higuchi, 1993). Due to a particular chemical property of resin acids, a white non-opaque coat about 1–2 mm thick formed on bark surfaces when the rosin tested was applied to carriers. This coat may have made it physically difficult for gray-sided voles to strip and masticate the bark.

After the bark of Japanese larch is eaten by gray-sided voles, the parts eaten are usually coated with the resin, and traumatic tissues develop from the surroundings onto the barked parts. The traumatic tissues are resinous, but we have observed a lot of the voles' feeding remains at the tissues (Personal observation, Unpublished data). This fact indicates that the larch resin does not physically or chemically deter the voles. A number of compounds contained in the rosin tested also exist in the resin of Japanese larch. However, some

Table 1 Values[a] of the bark area (cm^2) eaten by the voles in two-choice tests.

a) Rosin

Application rates	N^b	Treated carriers	Control carriers	p^c
5 mg/cm^2	8	26.8 ± 26.6	53.1 ± 28.6	< 0.01
10 mg/cm^2	8	12.7 ± 15.2	59.9 ± 25.2	< 0.01

b) Three wood tars

Materials	N^b	Treated carriers	Control carriers	p^c
Wood tars				
Alder	8	27.1 ± 30.9	81.8 ± 31.4	< 0.01
Larch	8	25.1 ± 33.4	82.6 ± 39.6	< 0.01
Birch	8	42.4 ± 43.7	71.1 ± 42.5	< 0.05
Wood vinegar				
Alder	8	42.1 ± 35.4	49.9 ± 31.5	> 0.05

c) Fractions from wood tar

Fractions	N^b	Treated carriers	Control carriers	p^c
Neutral	7	4.2 ± 11.9	59.3 ± 26.3	< 0.05
Phenol	7	10.9 ± 15.0	60.1 ± 26.2	< 0.05
Strong acid	7	17.5 ± 18.5	63.3 ± 25.2	< 0.05

[a]Values are means ± SD. [b]Numbers of the devices where a two-choice test carried out. [c]p-Values determined by the Wilcoxon signed-ranks test.

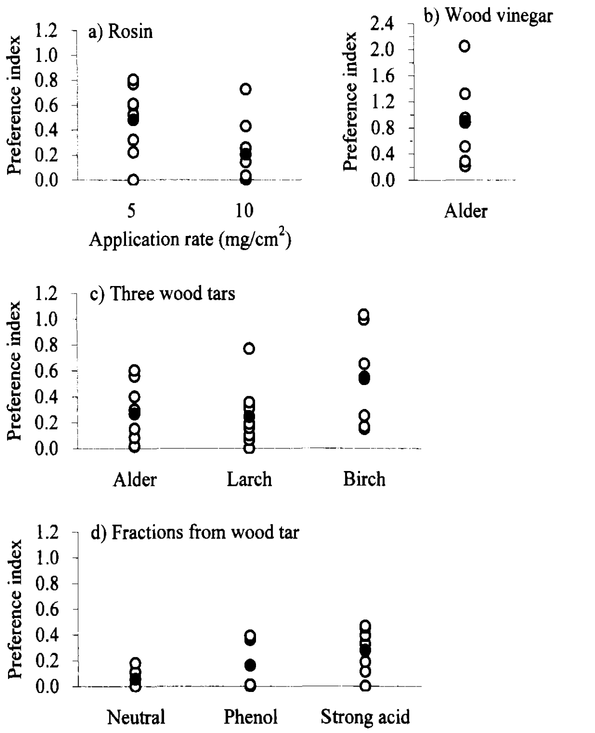

Fig. 4 Distribution of preference indices taken from two-choice tests. Note: Preference index (= the eaten area of treated carrier/that of control) followed the model of Reichardt *et al.* (1984); $N = 8$ in a), b), and c); $N = 7$ in d). Legends: ○, index at each device; ●, mean index.

compounds, such as longifolene, only exist in the rosin (Hirai, 2000). They may have been bioactive and chemical deterrents to the voles' barking.

The results for the rosin indicate that it has a smaller deterrent effect than the wood tars. However, it firmly fixes on bark, and therefore it may also be used to enhance the fixity of deterrents.

Wood tar is a mixture of different compounds such as phenols, acids, lactones, aldehydes, ketones, esters, ethers, frans, hydrocarbons, and bases (Soltes and Elder, 1981). These compounds are pyrolysates of lignin, cellulose, and hemicellulose which constitute wood (Soltes and Elder, 1981). The results for the wood tars showed that the mixture had deterrent effects on gray-sided voles.

The material-treated carriers were significantly less eaten compared to the controls for all cases of the wood tars tested. The results suggest that many kinds of wood tar, regardless of materials and manufacturing methods, may serve the purpose.

When it came to the wood vinegar, the treated carriers did not significantly differ in the eaten area from the controls. Wood vinegar contains many different compounds and some of them have biological functions (Yatagai and Unrinin, 1987; Yatagai *et al.*, 1988). However, the compounds in the wood vinegar did not reduce the voles' barking. In pretests, gray-sided voles often ate more of the treated carriers than the controls (Kojima *et al.*, 1999). Thus, the compounds in the wood vinegar may actually increase the voles' appetite.

The fractions from the alder tar reduced the voles' barking. The results suggest that all the fractions contained compounds that act as deterrents. In the tests of the fractions, gray-sided voles ate only the control carriers in some devices. This phenomenon was observed in 4 devices for the neutral fraction, 2 for the phenol, and 1 for the strong acid (Fig. 4d). It was not observed in the test of the pre-fractionated tar (Fig. 4c). In the test of each fraction, the application rate was the same as for the pre-fractionated tar (5 mg/cm^2). Therefore, the application rate of each compound related to the deterrent effect must have been larger in each fraction than in the pre-fractionated tar. This is probably why the treated carriers sometimes were not eaten at all during the tests. This phenomenon indicates that at the present application rate (5 mg/cm^2) some compounds in the fractions powerfully reduce the voles' barking. They also suggest that it is more effective to pick out the compounds from the mixture and use them individually rather than using whole wood tar. The preference indices for the neutral fraction have showed especially small values compared to the others (Fig. 4). Thus, this fraction is most promising.

From the late 1940s to the 1950s, Gohda (1952, 1956) studied the deterrent effects of coal tar, wood vinegar, and other repellents under field conditions. He has pointed out that the effects can not be expected from the materials when the gray-sided vole population density is high. We also tested the deterrent effects of the rosin and the wood tars, which were the same as in the present study, on a Japanese larch stand (Orihashi *et al.*, 2000). However, the effects were very slight, partly because the vole population density was very high during the test.

These results under field conditions indicate that the rosin and the wood tars have application limits when it comes to reducing the voles' damage. Therefore, continued use of rodenticide will be necessary when the vole population density is high. Moreover, to raise the application limits of the rosin and the wood tars, the compounds related to the deterrent effects should be extracted from the materials and used selectively as stated above. The specialization of the compounds related to the deterrent effects is an important subject that should be studied.

Wood tar contains some compounds that induce cancer or gene adduction (Schoket *et al.*, 1990; Schmid and Korting, 1996). If possible, such compounds should not be included in deterrents. It has yet to be scientifically proven whether rosin and wood tar are safe to apply in nature. Further studies should be carried out these points.

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