Distribution of *Typhula* species and varieties in Wisconsin, Utah, Michigan and Minnesota

The three fungi species responsible for most of the snow molds found on U.S. golf courses occupy distinct ecological niches.

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Typhula snow molds are basidiomycetes in which three species — *Typhula incarnata* Lasch ex. Fr., *T. ishikariensis* Imai and *T. phacorrhiza* Fries — and three varieties of *T. ishikariensis* — var. *ishikariensis*, var. *idahoensis* and var. *canadensis* — are the causes of the most important winter diseases of perennial grasses in the cool climates of the Northern Hemisphere (1). Typhula snow molds caused by *T. incarnata* and *T. ishikariensis* also are known as gray snow mold and speckled snow mold, respectively, and collectively they are called Typhula blight (4).

These fungi attack plants under persistent snow cover. In intensively managed turfgrasses, particularly creeping bentgrass (*Agrostis stolonifera* L.) and annual bluegrass (*Poa annua* L.), symptoms of the disease appear in spring after snow melt as straw-colored circular patches either of dead tissue embedded with sclerotia in the leaves, stems, crowns or roots of the plant or of loosely detached sclerotia, suspended in mycelium between leaves.

Snow mold caused by *T. ishikariensis* is considered harder to control than that caused by *T. incarnata* (11), possibly because *T. ishikariensis* is found primarily in regions with longer snow-cover duration, where plant carbohydrate reserves are more depleted and host plants are therefore more susceptible. Because some fungicides may only control a specific species or variety of *Typhula* (5), information on ecological aspects, including distribution of each species and variety in relation to environmental factors, is needed for effective control and management of *Typhula* snow molds.

Identification and distribution of *Typhula*

Historically, identification of *Typhula* species and varieties has relied on morphological characteristics (such as number, size and color of sclerotia) and mating compatibility studies, which have proved confusing (4). We used species-specific and variety-specific DNA markers to avoid identification problems. *Typhula ishikariensis* varieties have adapted to different habitats and environments, and weather conditions — such as temperature and snow cover — also are likely to affect the distribution of *Typhula* species. Understanding the impact of golf course management practices could be a key to controlling *Typhula* species on turf, because previous studies indicate that the distribution of *Typhula* species and varieties varies according to regions with different habitats (5) and substrates.

Materials and methods

Collection methods

In Wisconsin, we sampled 100 public golf courses that might not be able to afford snow mold fungicide applications on fairways. The courses were randomly chosen so that each USDA plant-hardiness zone in the study area and each number of estimated annual snow-cover days was represented equally. Another 35 golf courses (six in Utah, 15 in Michigan and 14 in Minnesota) were selected based on the likelihood of snow mold damage as assessed by local pathologists (Figure 1).

We collected data on mean temperature and total cumulative number of days with snow cover (snow-cover days), which have been suggested as major factors in snow mold disease development. The snow-cover days data from 100 locations were categorized into 20-day periods ranging from 71-90 days to 151-170 days (Table 1).

We collected colonized turfgrass tissues from fairways in spring 2001 and 2002. In Wisconsin, all 100 courses were sampled in 2001. Because of a lack of snow in 2002, we only sampled courses in northern Wisconsin (Figure 1). Of the 79 Wisconsin courses we visited in 2002, 65 had snow mold damage. We sampled courses in Utah in spring 2001, and courses in Michigan and Minnesota in spring 2002.

Sample identification

We used DNA (polymerase-chain-reaction) markers to identify *Typhula* species and varieties: *T. incarnata*, *T. phacorrhiza*, *T. ishikariensis*, *T. ishikariensis* var. *ishikariensis* and *T. ishikariensis* var. *canadensis*. We counted the number of each species or variety on each golf course or in each snow-cover-days zone.

Correlation of species distribution with environmental factors

We used mathematical analysis to examine the relationship between the absolute frequency of each species and variety present and the two environmental variables at each site (snow-cover days and mean temperature in degrees) in Wisconsin 2001 and 2002 (10).

Results

Environmental conditions

In Wisconsin, total snow-cover days ranged from 80 to 170 in 2001, and from 40 to 150 days in 2002 (Table 1). In 2001, 72 golf courses (72%) had more than 130 days of snow cover compared with nine courses (7%) in 2002. Winter was unusually warm in 2002, with frequent snow melt over most of the state. Estimated mean temperature ranged

Sampling sites

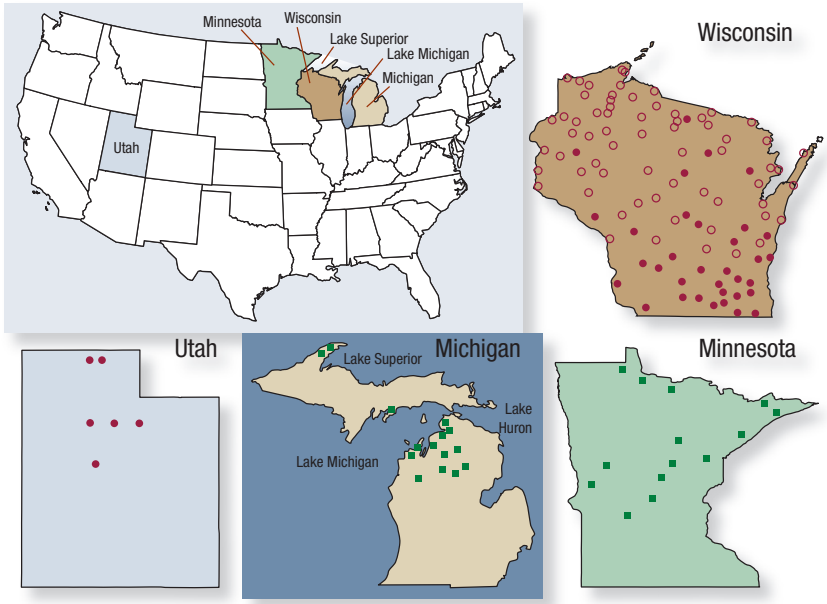


Figure 1. Sampling sites of Wisconsin, Utah, Michigan, and Minnesota states in 2001 and 2002. The symbols on the map of each state represent sampling sites, golf courses. Sites sampled in 2001= ● , in 2002= ■ , and sites sampled in 2001 and 2002= ○

Typhula snow mold in Wisconsin

		Typhula species		*T. ishikariensis* varieties			
Snow-cover days	No. golf courses	No. tested	TIN:TISH	No. tested	TISI:TCAN:TIDA	No. tested	TISI:TCAN
Year 2001							
71-90	5	94	84:6***	6	2:2:2	4	2:2
91-110	13	179	151:12***	12	6:0:6**	6	6:0
111-130	10	187	154:31***	31	15:14:2**	29	15:4 NS
131-150	31	525	196:217 NS	217	86:81:50**	167	86:81 NS
151-170	41	850	267:568**	568	252:226:90***	478	252:226 NS
Year 2002							
71-90	19	97	49:45 NS	45	22:19:4**	41	22:19 NS
91-110	16	165	38:123***	123	57:59:7***	116	57:59 NS
111-130	19	180	77:100 NS	100	27:57:16***	84	27:57**
131-150	9	127	50:73*	73	23:40:10***	63	23:40*

TIN, *Typhula incarnate*; TISH, *T. ishikariensis*; TISI, *T. ishikariensis* var. *ishikariensis*; TCAN, *T. ishikariensis* var. *canadensis*; TIDA, *T. ishikariensis* var. *idahoensis*.
*Significant at probability < 0.05; ** significant at probability < 0.01; *** significant at probability < 0.001. NS, no significant difference in the distribution of species.

Table 1. Frequency of occurrence of *Typhula* species and *T. ishikariensis* varieties according to estimated snow-cover days in golf courses in Wisconsin in 2001 and 2002 (copied from Chang et al., 2006).

from 24.0 F (-4.4 C) to 35.3 F (1.8 C) (mean 29.2 F [-1.6 C]) in 2001 and from 27.9 F [-2.3 C] to 37.3 F (2.9 C) (mean 32 F [0 C]) in 2002.

Typhula species composition

Of the 2,019 samples collected in 2001 from 100 Wisconsin golf courses, 1,835 (90.9%) were identified as *Typhula* (Table 2). The observed frequency of *T. incarnata*, *T. ishikariensis* and *T. phacorrhiza* deviated significantly from an expected 1:1:1 ratio, which would indicate that the species were distributed equally. The three varieties of *T. ishikariensis* (var. *ishikariensis*, var. *canadensis* and var. *idahoensis*) also deviated significantly from a 1:1:1 ratio. However, excluding var. *idahoensis* resulted in a frequency distribution of 43.3% for var. *ishikariensis* and 38.7% for var. *canadensis*, and this distribution did not deviate significantly from a 1:1 ratio.

Of the 680 samples collected from 65 Wisconsin golf courses in 2002, 569 (83.7%) were identified as *Typhula* species through DNA testing (Table 2). The observed frequencies of the three *Typhula* species in Wisconsin also deviated significantly from a 1:1:1 ratio, as did the occurrence of the three *T. ishikariensis* varieties (*ishikariensis*, *canadensis* and *idahoensis*) and the frequencies of var. *ishikariensis* and var. *canadensis*. We could not identify 111 samples using DNA testing.

In Wisconsin, the ratio of *T. incarnata* and *T. ishkariensis* significantly deviated from a 1:1 ratio in 2002, but not in 2001. The frequency of *Typhula incarnata* was higher than that of *T. ishikariensis* in 2001, but it was lower in 2002 (Table 1).

Of the 495 samples collected from 35 golf courses in Utah, Michigan and Minnesota, 92.9% were identified as *Typhula* species through DNA testing (Table 1). In all three states, the distribution of the three *Typhula* species deviated significantly from a 1:1:1 ratio.

The frequency of *T. incarnata* was significantly lower than that of *T. ishikariensis* in all states except Wisconsin in 2001. In Utah and Michigan, frequency of var. *ishikariensis* was significantly higher than the other varieties. However, frequency of var. *ishikariensis* and var. *canadensis* did not differ significantly in Minnesota or in Wisconsin in 2001. A total of 35 samples from Michigan, Minnesota and Utah were not identified through DNA testing.

Distribution of Typhula *species and* T. ishikariensis *varieties*

Based on estimated snow-cover days in Wisconsin in 2001 and 2002, *T. incarnata* was largely distributed in areas with fewer snow-cover days, but *T. ishikariensis* occurred more frequently in areas with more snow-cover days (Table 2). *Typhula phacorrhiza* samples were not included in the analysis because of its low frequency in all states (Table 2).

In all four snow-cover-day zones in Wisconsin in 2001, the frequencies of *T. incarnata* and *T. ishikariensis* were significantly different from each other (Table 2) except when total snow-cover days ranged from 131 to 150, in which case, the ratio of the two species approached 1:1. In 2002 in Wisconsin, observed frequencies of the two species deviated significantly from a 1:1 ratio in zones of 91-110 and 131-150 snow-cover days, but not in zones of 71-90 and 111-130.

Observed frequencies of the three *T. ishikariensis* varieties in all snow-cover-days zones, except 71-90 snow cover days in Wisconsin in 2001, significantly deviated from a 1:1:1 ratio in both years. The frequency of *T. ishikariensis* var. *ishikariensis* and var. *canadensis* did not deviate from a

Typhula snow mold on golf courses

		Occurrence of *Typhula* species			Occurrence of *T. ishikariensis* varieties			
State/year	No. of golf courses	No. tested	TIN:TPA:TISH	TIN:TISH	No. tested	TISI:TCAN:TIDA	No. tested	TISI:TCAN
Wisconsin, 2001	100	1,835	952:49:834***	952:834**	834	361:323:150***	684	361:323 NS
Wisconsin, 2002	65	569	214:14:341**	214:341***	341	129:175:37***	304	129:175**
Utah, 2001	6	50	15:4:31**	15:220***	31	29:2:0***	31	29:2***
Michigan, 2002	15	266	59:3:204**	59:204***	204	136:54:14***	190	136:54***
Minnesota, 2002	14	144	25:0:119**	25:119***	119	47:57:15***	104	47:57 NS

TIN, *Typhula incarnata*, TPA, *T. phacorrhiza*; TISH, *T. ishikariensis*; TISI, *T. ishikariensis* var. *ishikariensis*; TCAN, *T. ishikariensis* var. *canadensis*; TIDA, *T. ishikariensis* var. *idahoensis*.
*Significant at probability < 0.05; ** significant at probability < 0.01; *** significant at probability < 0.001. NS, no significant difference in the distribution of species and varieties.

Table 2. Frequency of occurrence of *Typhula* species and *T. ishikariensis* varieties sampled from golf courses in Wisconsin (2001 and 2002), Utah (2001), Michigan (2002) and Minnesota (2002).

The species *Typhula incarnata* is known as gray snow mold. **Photos by G. Jung**

Speckled snow mold is the common name for the turf disease caused by *Typhula ishikariensis*.

1:1 ratio in all zones in both years, except for two zones (111-130 and 131-150) in 2002. Zones 71-90 and 91-110 in 2001 were not included in the statistical analysis because of the low frequency of var. *ishikariensis* and var. *canadensis*.

Discussion

Typhula incarnata and *T. ishikariensis* occurred frequently in all states, but *T. phacorrhiza* was rare or absent (Table 1). All three varieties of *T. ishikariensis* were found in all states except Utah, where var. *idahoensis* was not reported. The absence of species and varieties reported from Minnesota and Utah may be due to sampling error or the effect of environmental conditions during the sample years.

In 2001, *T. incarnata* was the most common species and was distributed relatively evenly across Wisconsin (99 golf courses), with broad distribution across snow-cover-day zones, compared to *T. ishikariensis* (76 golf courses) (Table 2). As days of snow cover increased, the relative frequency of *T. incarnata* decreased and the frequency of *T. ishikariensis* increased significantly, suggesting that the habitats of the two species were different (Table 2). Unlike *T. ishikariensis*, *T. incarnata* has been shown to adapt to less favorable environments for snow mold development, such as shallower snow cover and fewer snow-cover days. Although *T. incarnata* is considered less virulent than *T. ishikariensis*, *T. incarnata* may be more saprotrophic (saprotrophic organisms feed on dead or decaying matter) and therefore occupy a broader ecological niche (5).

During the warm winter of 2002, *T. incarnata* was found in Wisconsin significantly less often than *T. ishikariensis* (Tables 1, 2), indicating the major effect of environment on *Typhula* occurrence overall. Because the courses sampled in 2002 are in northern Wisconsin, which has provided ideal habitat for *T. ishikariensis* for a long time, the higher relative frequency of *T. ishikariensis* in 2002 might be due to its greater inoculum potential. A combination of environmental factors other than those studied here also may have played a role in the higher frequency in 2002. In Utah, Minnesota and Michigan, the lower frequency of *T. incarnata* seems to be related to the more favorable habitat for *T. ishikariensis* — heavy snowfall caused by high altitude or lake effect (Utah), lake effect (Michigan) and northern climate (Minnesota) (7,8).

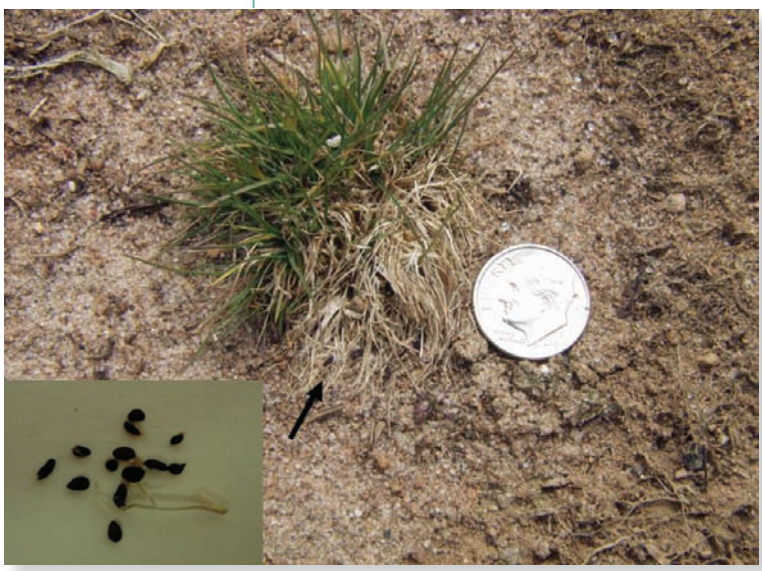
Analysis of the 2001 Wisconsin data shows that the *T. incarnata* species favored a habitat less affected by snow and cold temperatures, whereas the *T. ishikariensis* varieties preferred more snow-cover days and colder temperatures. The exception to this is the unusual 2002 winter, where data analysis suggests that snow-cover days were not a significant factor in distribution of *T. ishikariensis* varieties (Table 2).

Typhula phacorrhiza

Typhula phacorrhiza was least common in all states and was not found at all in Minnesota. We found that *T. phacorrhiza* occurred relatively evenly throughout Wisconsin in both years. The reported distribution of *T. phacorrhiza* throughout temperate winter climates agrees with our analysis, which found the fungus where snow-cover days were fewer and mean temperatures were higher. This niche may reflect the low saprotrophic activity of *T. phacorrhiza*.

Typhula ishikariensis

Typhula ishikariensis was distributed across all four states included in this study and occurred more frequently in regions with more snow-cover days and lower mean temperature (Table 2). In a previous study, *T. ishikariensis* was found to be



Sclerotia of *Typhula phacorrhiza* and partially damaged turf (indicated by arrow). This fungus was the least common of all the *Typhula* species found in this study.

common where there were more than 100 snow-cover days, but we found it in areas with fewer than 100 snow-cover days. Therefore, weather conditions other than snow-cover days, mean temperature and host species also may play important roles in the survival and occurrence of *T. ishikariensis*. Based on these results, we must conclude that *T. ishikariensis* can be a potential problematic pathogen in warmer areas with fewer snow-cover days given the proper habitat. More research must be performed to identify whether other factors are key to *T. ishikariensis* occurrence during warmer winters.

All three varieties were found in closely related ecological habitats in 2001. This may be a result of harsh environmental conditions that resulted in an ecological separation of *T. ishikariensis* varieties from *T. incarnata* and *T. phacorrhiza*, but no separation within the species.

Typhula ishikariensis var. *idahoensis* showed the lowest frequency in all states compared with the other two varieties. The low frequency of this variety could be explained by its unstable genetic background, which reduced its ability to reproduce, or its specific habitat could be different from that of var. *canadensis* and var. *ishikariensis*. In Wisconsin during 2002, *T. ishikariensis* var. *ishikariensis* occurred less frequently than var. *canadensis*. The distribution of *T. ishikariensis* var. *idahoensis* among habitats based on snow-cover days and mean temperature was more similar to that of var. *canadensis* than that of var. *ishikariensis* (8).

In 2001, there was much less separation of the varieties based on environmental factors than in 2002, suggesting that the distribution of *T. ishikariensis* varieties can be significantly affected by harsh environmental conditions. These trends also were present in the data from the other states. In areas with more snow-cover days but higher temperatures, such as Utah and Michigan, var. *ishikariensis* was found more often. In colder habitats with fewer snow-cover days, such as Minnesota, var. *ishikariensis* and var. *canadensis* were found with equal frequency throughout the collection area.

Conclusions

Typhula incarnata, *T. phacorrhiza* and *T. ishikariensis* occupy unique ecological niches. *Typhula incarnata* and *T. ishikariensis* were the most common species. *Typhula incarnata* favored warmer areas, but showed strong ecological adaptability, while *T. ishikariensis* varieties were more frequently distributed in colder regions with longer snow-cover days. Based on mathematical analysis, snow-cover days and mean temperature were highly correlated with the frequency of *Typhula* species and *T. ishikariensis* varieties in Wisconsin in 2001. Based on the 2002 data, *T. incarnata*, *T. phacorrhiza* and *T. ishikariensis* are ecologically distinct, but the three *T. ishikariensis* varieties

Sclerotia of *Typhula ishikariensis*. This species occurs in areas with longer snow-cover duration.

Two species of snow mold, *Typhula incarnata* (top) and *T. ishikariensis* (bottom), are active in the same area.

Different stages of snow mold infestation and recovery are evident on this golf course turf.

are not adapted to different environments, especially given the data from winter 2002, which was unusually warm.

Future research

Snow-cover days was the best variable based on this study, but it did not explain a majority of the variation, suggesting that more precise measurements (depth, longest duration and frequency of snow melts) of snow cover and soil temperature may give more detail in future studies.

Future research should focus on potential competition among *Typhula* species and varieties.

Another area needing further study is the robustness of current *Typhula* identification methods. Future efforts will investigate samples left unidentified using current DNA and molecular methods or microscopic evaluation. Identification of these turf pathogens is important for understanding other *psychrophilic* fungi (fungi that thrive at low temperatures) that could potentially interact with *Typhula* species and for designing effective management strategies.

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Literature cited

1. Årsvoll, K., and J.D. Smith. 1978. *Typhula ishikariensis* and its varieties, var. *idahoensis* comb. nov. and var. *canadensis* var. nov. *Canadian Journal of Botany* 56:348-364.
2. Dellaporta, S.L., J. Wood and J.B. Hickes. 1983. A plant DNA minipreparation; version II. *Plant Molecular Biology Reporter*1:19-21.
3. Gaudet, D.A., A. Laroche and M. Yoshida. 1999. Low temperature-wheat-fungal interactions: A carbohydrate connection. *Physiologia Plantarum* 106:437-444.
4. Hsiang, T., N. Matsumoto and S.M. Millett. 1999. Biology and management of Typhula snow molds of turfgrass. *Plant Disease* 86:788-798.
5. Matsumoto, N. 1994. Ecological adaptations of low temperature plant pathogenic fungi to diverse winter climates. *Canadian Journal of Plant Pathology* 16:237-240.
6. Matsumoto, N., A.M. Tronsmo and T. Shimanuki. 1996. Genetic and biological characteristics of *Typhula ishikariensis* isolates from Norway. *European Journal of Plant Pathology* 102:431-439.
7. National Operational Hydrologic Remote Sensing Center. 2001. 2001 North American airborne and satellite snow data. CD-ROM. NOHRSC, Office of Hydrology, National Weather Service, NOAA, Chanhassen, Minn.
8. National Operational Hydrologic Remote Sensing Center. 2002. 2002 North American airborne and satellite snow data. CD-ROM. NOHRSC, Office of Hydrology, National Weather Service, NOAA, Chanhassen, Minn.
9. Schneider, E.F., and W.L. Seaman. 1986. *Typhula phacorrhiza* on winter wheat. *Canadian Journal of Plant Pathology* 8:269-276.
10. Ter Braak, D.J.F. 1987. Canonical correspondence analysis: A new eigenvector technique for multivariate direct gradient analysis. *Ecology* 67:1167-1179.
11. Worf, G.L. 1988. Evaluating snow mold control. *Golf Course Management* 58:70-80.

GCM

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The research says

- Samples of three *Typhula* species and *T. ishikariensis* varieties were collected from 135 golf courses in Wisconsin, Utah, Michigan and Minnesota.
- Sites were identified where each *Typhula* species or variety occurred frequently within the study area, and climatic conditions and biotic factors (species competition and interaction) were correlated with that distribution data.
- The three *Typhula* species were found to occupy distinct ecological niches, but the three *T. ishikariensis* varieties are not adapted to different environments.
- A better understanding of how *Typhula* species and varieties are influenced by their environment can help researchers develop more-effective strategies of snow mold control.