Short Communication

Delayed Emergence and Reduced Body-weight of *Xeris spectrum* (Hymenoptera: Siricidae) Due to Nematode Infection

Hideshi Fukuda[1, 2] and Naoki Hijii

Laboratory of Forest Protection, School of Agricultural Sciences, Nagoya University, Nagoya 464−01, Japan.

Woodwasps (Siricidae) are primitive hymenopterans whose larvae feed primarily on the sapwood of various coniferous and hardwood trees. Most woodwasp species are symbiotically associated with specific fungi, *Amylostereum* spp. The symbiotic fungi are simultaneously inoculated into the sapwood of new host trees at the time of woodwasps' oviposition (Morgan, 1968; Talbot, 1977). Recently, in Japan, felled trees left on the forest floor following artificial thinning for plantations of Japanese cedar, *Cryptomeria japonica* D. Don, and Japanese cypress, *Chamaecyparis obtusa* Sieb. et Zucc. has allowed a gradual increase in the overall population levels of the woodwasps because most woodwasps attack these freshly felled trees. Increased populations of the woodwasps cause them to oviposit into the living trees, and thus discoloration and deterioration of wood tissue induced by the symbiotic fungi have often degraded the commercial value of wood (Shibata, 1984; Yamada and Okuda, 1987).

The control of woodwasps is difficult because they bore deeply in the wood during their larval stage. In Australia where *Pinus radiata* D. Don was infested heavily with the woodwasp, *Sirex noctilio* Fabricius, attempts at biological control of this species have been intensive (Madden, 1988). In particular, biological control using a parasitic nematode species, *Deladenus siricidicola* Bedding, has brought about excellent results (Bedding, 1993; Bedding and Akhurst, 1974; Madden, 1988; Nuttall, 1980; Talbot, 1977; Zondag, 1967, 1975). In this paper, we report unidentified parasitic nematodes from two woodwasp species, *Xeris spectrum* Linné and *Urocerus japonicus* Smith, which emerged from a tree of *Cryptomeria japonica*, and examine the effect of nematode infection on the reproduction of *X. spectrum*.

Materials and Methods

1 Woodwasps and parasitic nematodes

X. spectrum is widely distributed in many parts of the world including Asia, Europe and North America (Morgan, 1968; Takeuchi, 1962). In Japan, about a half of the populations of this species have an univoltine life cycle, while others complete their life cycle in two years (Kanamitsu, 1978). *X. spectrum* has no symbiotic fungi because it lacks intersegmental sacs to preserve fungal spores (Morgan, 1968).

U. japonicus is distributed all over Japan (Takeuchi, 1962). The life cycle of this species is, in most cases, completed within one year. *U. japonicus* is symbiotically associated with one species of *Amylostereum* (Kanamitsu, 1978).

Parasitic nematodes from *X. spectrum* and *U. japonicus* showed morphological characteristics of the superfamily Sphaerularioidea such as possessing stylet without oesophageal median bulb (Remillet and Laumond, 1991). However, we could not identify the nematodes closer because precise observations of the adult nematodes were not possible.

2 Experimental procedures

In August, 1992, several trees of *C. japonica* and *C. obtusa* were felled through artificially thinning and left on the forest floor in a plantation at Owase, Mie Prefecture, Japan. In June, 1993, one felled *C. japonica* tree infested with woodwasps was selected as a sample tree. The tree, aged 35 yr, was cut into 17 1-m long logs, and 12 logs with many woodwasp oviposition holes were selected and transferred to an outdoor cage at the Nagoya University Campus in Nagoya City. Woodwasps emerged from the logs between 1993 and 1994 were collected everyday and the fresh body-weight of each adult was measured immediately after collection. The female body-weight in our study included the weight of eggs because most eggs had already matured at the time of emergence. They were then transferred to glass jars (15 cm diam. × 20 cm high) and reared on 5% sucrose solution to determine longevities under laboratory conditions at about 25℃. Soon after the female adults died, we observed the status of the nematode infection in the ovaries for all females by dissecting their abdomen under a stereo-microscope. The number of mature eggs was counted for most of the females whose ovaries had not withered or deformed due to nematode infection.

Statistical analyses were performed using the SPSS computer program (SPSS, 1993).

Results

1 Percentage of nematode infection

In 1993, 48 *X. spectrum* females and 14 *U. japonicus* females emerged from the sample logs. No nematode infection was found in *X. spectrum*, whereas three *U. japonicus* females (21%) were infected with nematodes. In 1994, 26 of 47 emerging *X. spectrum* females (55%) were infected with nematodes, and no *U. japonicus* emerged.

[1] Corresponding author.
[2] Research Fellow of the Japan Society for the Promotion of Science.

2 Changes in the body-weight of *X. spectrum* with the time of emergence in relation to the percentage of nematode infection

There was an obvious single period of emergence in the 1993 population, from early August to mid-September, whereas there were two periods of emergence in the 1994 population (Fig. 1). The first period was from early May to late May and the second from late May to late June (Fig. 1). The mean fresh body-weights of woodwasp males that emerged in 1993, and during the first period in 1994 were similar (ANOVA with Scheffe's multiple range test, $p > 0.05$), and were significantly larger than that of males emerging in the second period in 1994 (ANOVA with Scheffe's multiple range test, $p < 0.05$) (Table 1, Fig. 1).

Table 1 Fresh body-weight (mg) of *X. spectrum* that emerged in 1993 and 1994 (mean ± SE).

	♂	♀
1993	23.7 ± 1.7[a]	44.6 ± 2.1[a]
1st period 1994	24.5 ± 2.6[a]	63.2 ± 5.7[b]
2nd period 1994	13.3 ± 1.4[b]	29.9 ± 2.2[c]

Means followed by the same letter for each sex are not significantly different ($p > 0.05$; Scheffe's multiple range test)

The mean body-weight of *X. spectrum* females in the first emergence period in 1994 was significantly larger than that of the 1993 population, which was in turn larger than that of the second period in 1994 (ANOVA with Scheffe's multiple range test, $p < 0.05$) (Table 1, Fig. 1). No females that emerged in the first period in 1994 were infected by the nematodes, whereas the most in the second period of emergence in 1994 were infected (Fig. 1). The mean body-weight ± SE of infected females (28.9 ± 1.6 mg) was smaller than that of the uninfected (52.8 ± 4.7 mg) in the 1994 population (t-test, $p < 0.05$) (Fig. 2).

3 Fecundity

In the present study, only four individuals of 24 infected *X. spectrum* females suffered from ovarian dysfunction and reduction in fecundity (about 17%). Most juvenile nematodes in other infected woodwasps were packed between the eggs and the ovary wall, and there were no symptoms of deterioration of the ovaries.

Mean egg production of infected females was less than that of uninfected females (Table 2). However, there was a strong positive correlation between the total number of eggs produced by a female and the fresh body-weight of females, irrespective of nematode infection, except for the four indi-

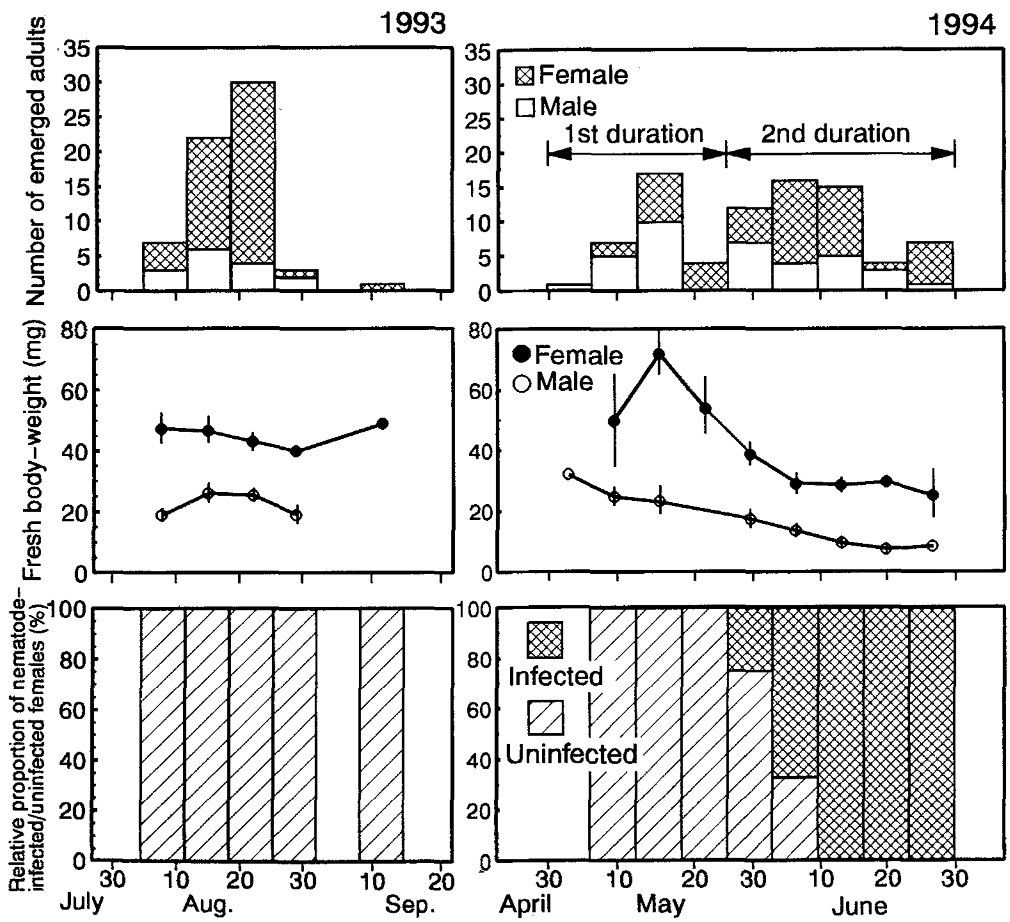

Fig. 1 Seasonal changes in number of emerged adults per week (top), in body-weight (mean ± 1SE) (middle) and in the relative proportion of nematode-infected/uninfected females (bottom) of *X. spectrum* in 1993 and 1994.

viduals with ovarian dysfunction ($n = 20, r = 0.89, p < 0.01$ for infected, $n = 18, r = 0.95, p < 0.01$ for uninfected) (Fig. 3). Moreover, there was no significant difference between the two regression lines in both slopes and intercepts (t-test, $p > 0.05$), indicating that the fecundity-weight relationship was represented by a single regression line ($n = 38, r = 0.95, p < 0.01$).

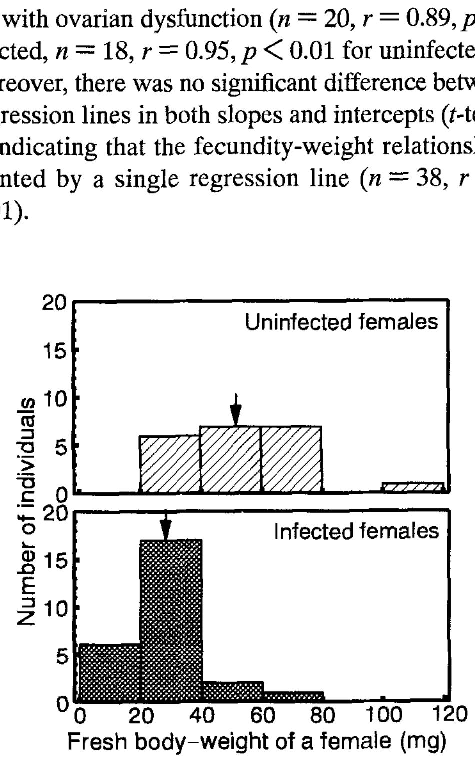

Fig. 2 Frequency distributions of fresh body-weights of *X. spectrum* females uninfected (top) and infected (bottom) by nematodes. Arrows indicate mean values.

Table 2 Total number of eggs and longevity of females of *X. spectrum* emerged in 1994 that were either infected or not infected by nematodes (mean ± SE).

	Total number of eggs	Longevity (days)
Infected	67.3 ± 7.2	4.1 ± 0.2
Uninfected	128.4 ± 10.0*	4.0 ± 0.2^{ns}

* $p < 0.01$, ^{ns} not significant; t-test.

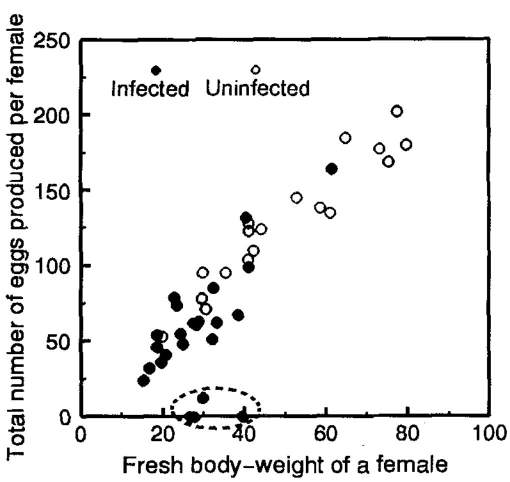

Fig. 3 Relationship between total number of eggs produced by a female adult and fresh body-weight of a female adult in *X. spectrum*. The four individuals with ovarian dysfunction in the dashed circle were excluded from the analysis.

4 Longevity

There was no significant difference in mean longevity between nematode-infected and uninfected *X. spectrum* females that emerged in 1994 (t-test, $p > 0.05$) (Table 2).

Discussion

No females that emerged in the first period in 1994 were infected by the nematodes, whereas the most in the second period of emergence in 1994 were infected. This result suggests that nematode-infected *X. spectrum* tends to emerge later than uninfected ones. A similar trend was reported also in the case of *Sirex noctilio* in Australia (Neumann *et al.*, 1993).

It has been shown that for *Sirex* species the total number of eggs produced per female, *i.e.* potential fecundity, was positively correlated with the female body size (Madden, 1974; Fukuda *et al.*, 1993). Also in this study, there were strong positive correlations between the total number of eggs produced per female *X. spectrum* and the fresh body-weight in both infected and uninfected populations (Fig. 3). Infected females, however, tended to have smaller body-weights than uninfected ones (Fig. 2), and they might therefore have smaller fecundities due to smaller body-weights.

Thus, in this study, nematode-infected females of *X. spectrum* tended to emerge later and have smaller body-weights than those uninfected (Figs. 1 and 2), but in most cases the parasitism of the nematodes has directly caused suppression of ovarian development. Thus, the nematodes probably have reduced the fecundity of *X. spectrum* indirectly through reduction in the body-weight (Figs. 2 and 3). Nematodes would not have significantly contributed to suppression of the *X. spectrum* population as compared to the case of *S. noctilio* in Australia (Nuttall, 1980), because there was little deterioration in the ovaries of the woodwasps.

According to the morphological characteristics, the nematodes involved in this study are considered to belong to the superfamily sphaerularioidea although they could not be identified exactly as at the species level. Among sphaerularioids, no nematodes other than *Deladenus* spp. are known as parasites of woodwasps (Remillet and Laumond, 1991). Bedding and Akhurst (1978) and more recently Kosaka (pers. com.) have confirmed *Deladenus rudyi* as the nematode species that commonly parasitized *U. japonicus* and *X. spectrum* infesting *C. japonica* in Japan. Therefore, we suspect the species of nematodes detected in the present study is probably the same species, *D. rudyi* or closely related species.

Bedding (1972, 1993) reported that some strain of *D. siricidicola* sterilized *S. noctilio* by penetration of the juvenile nematodes into the eggs in the ovaries of the wasps, which also caused suppression of ovarian development and severe reduction in the number and size of eggs produced. In the present case, however, only four individuals (about 17%) among the 24 infected woodwasps suffered ovarian dysfunction and reduction in fecundity independent of body size (Fig. 3). Most juvenile nematodes in other infested woodwasps were packed between the eggs and the ovary wall, and there were no symptoms that the nematodes affected reproduction of the woodwasps as was seen in *S. noctilio*. These observations suggest that the nematodes do not always sterilize *X. spectrum* even if they belong to the genus *Deladenus*.

Effects of nematode infection on woodwasps have been suggested to vary depending on nematode species (Madden, 1988) and/or nematode strains (Bedding, 1993). Moreover, it was reported that effects of a sphaerularioid nematode on its bark beetle hosts were altered also by burden of nematodes (Ashraf and Berryman, 1970). Further evaluation for the effects of nematode infection on the reproduction of woodwasps will require identification of nematodes at the strain level as well as the species level and determination of the burden of nematodes on the woodwasps.

The authors thank Prof. E. Shibata, Nagoya University, for his critical review of the manuscript. We also thank Dr. H. Kosaka, Forest and Forest Products Research Institute, for his technical advice for the experiment concerning the nematode, Dr. H. Kajimura, Nagoya University, and Mr. A. Sano, Mie Prefecture, for their invaluable suggestions, and Mr. H. Nakajima, Owase City Agr. and For. Sec., and members of the Laboratory of Forest Protection for their helpful support in collecting materials.

This study was supported in part by a Grant-in-Aid for Scientific Research from the Japanese Ministry of Education, Science, Sports, and Culture (No.06454090 and 80003292).

Literature cited

Ashraf, M. and Berryman, A.A. (1970) Biology of *Sulphuretylenchus elongatus* (Nematoda: Sphaerulariidae), and its effect on its host, *Scolytus ventralis* (Coleoptera: Scolytidae). Can. Ent. 102: 197-213.

Bedding, R.A. (1972) Biology of *Deladenus siricidicola* (Neotylenchidae) an entomophagous-mycetophagous nematode parasitic in siricid woodwasps. Nematologica 18: 482-493.

Bedding, R.A. (1993) Biological control of *Sirex noctilio* using the nematode *Deladenus siricidicola*. *In* Nematodes and the biological control of insect pests. Bedding, R.A., Akhurst, R.J., and Kaya, H.K. (eds.), 178pp, CSIRO, Australia, 11-20.

Bedding, R.A. and Akhurst, R.J. (1974) Use of nematode *Deladenus siricidicola* in the biological control of *Sirex noctilio* in Australia. J. Aust. Ent. Soc. 13: 129-135.

Bedding, R.A. and Akhurst, R.J. (1978) Geographical distribution and host preferences of *Deladenus* species (Nematoda: Neotylenchidae) parasitic in siricid woodwasps and associated hymenopterous parasitoids. Nematologica 24: 286-294.

Fukuda, H., Kajimura, H., and Hijii, N. (1993) Fecundity of the woodwasp, *Sirex nitobei* Matsumura, in relation to its body size. J. Jpn. For. Soc. 75: 405-408.

Kanamitsu, K. (1978) Woodwasps and their hymenopterous parasitoids in Japanese conifers. Kontyû, Tokyo 46: 498-508. (in Japanese with English summary).

Madden, J.L. (1974) Oviposition behavior of the woodwasp, *Sirex noctilio* F. Aust. J. Zool. 22: 341-351.

Madden, J.L. (1988) *Sirex* in Australasia. *In* Dynamics of forest insect populations: Patterns, causes, implications. Berryman, A.A. (ed.), 603pp, Plenum Press, New York, London, 407-429.

Morgan, F.D. (1968) Bionomics of Siricidae. Ann. Rev. Ent. 13: 239-256.

Neumann, F.G., Collett, N.G., and Smith, I.W. (1993) The Sirex wasp and its biological control in plantations of radiata pine variably defoliated by *Dothistroma septospora* in north-eastern Victoria. Aust. For. 56: 129-139.

Nuttall, M.J. (1980) Nematode parasites of *Sirex*, *Deladenus siricidicola* Bedding (Nematoda: Neotylenchidae). N. Z. For. Serv., For. Res. Inst., Forest and Timber Insects in New Zealand 48: 1-8.

Remillet, M. and Laumond, C. (1991) Sphaerularioid nematodes of importance in agriculture. *In* Manual of agricultural nematology. Nickle, W.R. (ed.), 1035pp, Marcel Dekker, Inc., New York, Basel and Hong Kong, 967-1024.

Shibata, E. (1984) Injury of polished logs of Japanese cedar, *Cryptomeria japonica* by *Urocerus japonicus*. Shinrin-Boeki (Forest Pests) 33: 12-14. (in Japanese)

SPSS (1993) SPSS for Windows, Release 6.0J, SPSS, Chicago.

Takeuchi, K. (1962) Insecta Japonica, Hymenoptera: Siricidae. Ser. 2 Part 2. Hokuryukan Publishing Co., Ltd., Tokyo. (in Japanese)

Talbot, P. H. B. (1977) The *Sirex-Amylostereum-Pinus* association. Ann. Rev. Phytopathol. 15: 41-54.

Yamada, T. and Okuda, K. (1987) Wood discoloration of hinoki and sugi living trees inoculated with *Amylostereum* sp. symbiotic to the Japanese horntail (*Urocerus japonicus* Smith). Trans. 98th Ann. Mtg. Jpn. For. Soc., 515-516. (in Japanese)

Zondag, R. (1967) Biological control of *Sirex noctilio*. N. Z. For. Serv. Rep. For. Res. Inst. 1966, 62-64.

Zondag, R. (1975) Controlling sirex with a nematode. Proc. 28th N. Z. Weed Pest Cont. Conf.: 196-199.

(Accepted May 7, 1997)