Impact of imidacloprid on hemlock woolly adelgid (*Adelges tsugae*) and water quality at Mt. Lake, Virginia

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ABSTRACT

Two groups of hemlock trees were treated with imidacloprid using Kioritz® soil injectors and one group of trees with Mauget stem injection capsules from 2001 to 2003. In one group of soil injected trees the density of HWA was reduced by 35%, 14 months after the first application and two months after the second application. Tree health declined in all years but not as much as for treated trees in this group. HWA density was reduced by 52% in a second group of soil injected trees, three months after the first treatment and 93% one year after the second treatment. Tree health remained unchanged for three years for all trees, treated and untreated. Stem-injected trees showed a 52% reduction in HWA three months after the first treatment and an 87% reduction one year after the second injection. Tree health of these trees did not change and were no different that the untreated trees. Both groups of trees (soil injected and stem injected) had similar health indices, and both treatment methods are providing a similar protection from HWA. Treated trees were located more than 50 m from a stream or the lake. Imidacloprid was detected in lake and spring water in concentrations ranging from less than 0.02 ppb to 1.7 ppb in lake water and 3.5 ppb in spring water. The density of invertebrates in the springs did not change from 2001 – 2003. However, caution must be used when applying imidacloprid near waterways, especially in rocky well-drained soil.

KEYWORDS:

Imidacloprid, hemlock woolly adelgid, *Adelges tsugae*, water quality, tree health, Imicide®, Merit®.

INTRODUCTION

Mountain Lake Resort is located in Giles County, Virginia. This 1,052 ha resort is situated on Salt Pond Mountain (1,000–1,200 m) with a 22 ha natural lake. Hemlock woolly adelgid (HWA) *Adelges tsugae* Annand began infesting *Tsuga* spp. in southwest during the mid-1990s. HWA was first noticed in the resort area in 1999. Old growth stands of hemlocks encircle the lake, with many trees over 100 cm diameter at breast height (DBH). The hemlocks (*Tsuga canadensis* (L.) Carrière) surrounding the lake are the dominant species in this unique climax forest. In order to preserve as many trees as possible the resort contracted the authors and a chemical control program was begun in 2001.

Based on the success of imidacloprid (Steward and Horner 1994, Tatter et al. 1998, Steward et al. 1998, Cowles and Cheah 2002, Silcox 2002, Webb et al. 2003), this product was used to control HWA at Mt. Lake. The effectiveness of imidacloprid treatments on HWA, tree health, migration of imidacloprid into the lake, and impact on stream invertebrates were evaluated.

METHODS

Two methods of imidacloprid injection, soil and stem injections, were used. To minimize imidacloprid migrating into the water table or streams in the area, stem injections were used where treated trees were more than 50 m from the lake, springs, or streams.

Three groups of hemlock trees (84, 26, and 32, respectively) were treated between 2001 and 2003. Groups I and II were treated with imidacloprid soil injections and Group III with stem injections. Based on their probability of survival, trees that were less than 50% defoliated and had new growth were selected. Tree DBH ranged from 5 to 128 cm, with a mean of 17 cm. Groups I and II were treated by soil injection with imidacloprid (Merit® 75 WP) at a rate of 0.75 g/cm DBH (0.55 g a.i./cm DBH) with Kioritz® soil injectors in April of 2001, 2002, and 2003. Soil treatments were made using the Basal System (Silcox 2002). Injections were made around the tree, 10 to 20 cm from the tree base. Trees in Group III were close to a stream (Pond Drain) and were stem injected with imidacloprid (Imicide® 10%) at the rate of one 3 ml Mauget (J.J. Mauget Company, Arcadia, California) capsule/5 cm DBH in April 2002 and April 2003.

A subset of treated trees was paired with untreated trees for each group. The untreated trees selected were similar in size and located up slope and at least 15 m away from its paired treated tree. To determine the density of HWA, the number of live HWA adult sistens in March and adult progrediens in June were counted on 30 cm of the terminal branches on the north, south, east, and west aspects of each treated and untreated tree.

Tree health was evaluated for each treated and untreated tree once during the growing season by recording the percent crown density, live crown ratio, live branches, live tips, and new foliage. These five parameters were summed and divided by 5 to obtain a health index. A value of 100 would be a perfect tree and 0 would indicate a dead tree.

Water samples (1.9 l) were taken at four locations in the lake and from four springs that flowed into the lake to determine if imidacloprid was migrating through the soil and into the lake and water-table at Mountain Lake. Samples were analyzed at Virginia Tech Pesticide Residue Lab using high performance liquid chromatography (HPLC).

To determine the impact of imidacloprid on stream invertebrates, all springs flowing into the lake were sampled in the months of April and June of 2001, 2002, and 2003. Sampling was done each spring between the lake and the forest edge. For each year of sampling, fifty stones were picked up and the invertebrates found were collected at each sample site. The water level in these springs was too shallow to use a net. Due to the rise in the lake level in 2003 the springs that were sampled became submerged and invertebrate sampling was not possible.

Tree health indices for each treatment group and the number of invertebrates recorded from the springs at each sample date were analyzed using one-way analysis of variance (ANOVA) and the Tukey-Kramer HSD test (SAS Institute 1989).

RESULTS

GROUP I

No statistically significant difference in the HWA density was found between treated and untreated trees 10 months after treatment (Table 1, Figure 1). At this sample date (Feb. 15, 2002) there were 1.9 HWA per cm on the treated trees and 1.5 HWA per cm on the untreated trees. This is approximately a 37% drop in the HWA density from the previous year and is likely due to the natural decline in HWA several years after the initial infestation (McClure 1991). Ten months should be a more than adequate time for imidacloprid to enter the hemlock branch tips. Tatter et al., (1998) reported that lethal concentrations of imidacloprid occurred 12 weeks after soil injections. A possible reason for no treatment effect on HWA is that an insufficient amount of imidacloprid reached the branch tips due to below normal rainfall for several months after the first application. The highly organic, loose rocky soil may have resulted in low rates of binding with soil particles. However, after the second application on April 6, 2002, sampling on June 18, 2002, showed a 35% reduction in HWA on the treated trees compared with the untreated trees. As planned, no soil injections were made to this group of trees in 2003 and 2004 and the HWA population was very low on treated and untreated trees.

Due to several years of drought and HWA infestation hemlock health declined significantly in 2002 (Table 2). There was no difference in tree health between the treated and untreated trees until 2003, the second year after the first treatment. The health index of the treated trees was approximately 52 in 2003 and 2004 while the health index of the untreated trees declined from 44 to 20. The reduction in HWA population density caused by imidacloprid may have prevented the treated trees from declining significantly in health. Recovery of tree health following imidacloprid treatments was not as great as reported by Webb et al. (2003), who reported dramatic recovery of tree health following imidacloprid treatments. Their study was done in a residential landscape and differences in soil type may have contributed to the greater recovery in health compared to our study done in a forest with rocky, well-drained soil.

GROUP II

Three months after treatment the number of HWA on the treated trees (1.14/cm) was 52% lower than the untreated trees (2.39 / cm) (Table 3, Figure 1). In 2003 the HWA population was very low on the treated and untreated trees due to the natural decline that HWA exhibits several years after initial infestation. HWA density was also very low in 2004; however, there was a 93% reduction in HWA on the treated trees compared with the untreated trees.

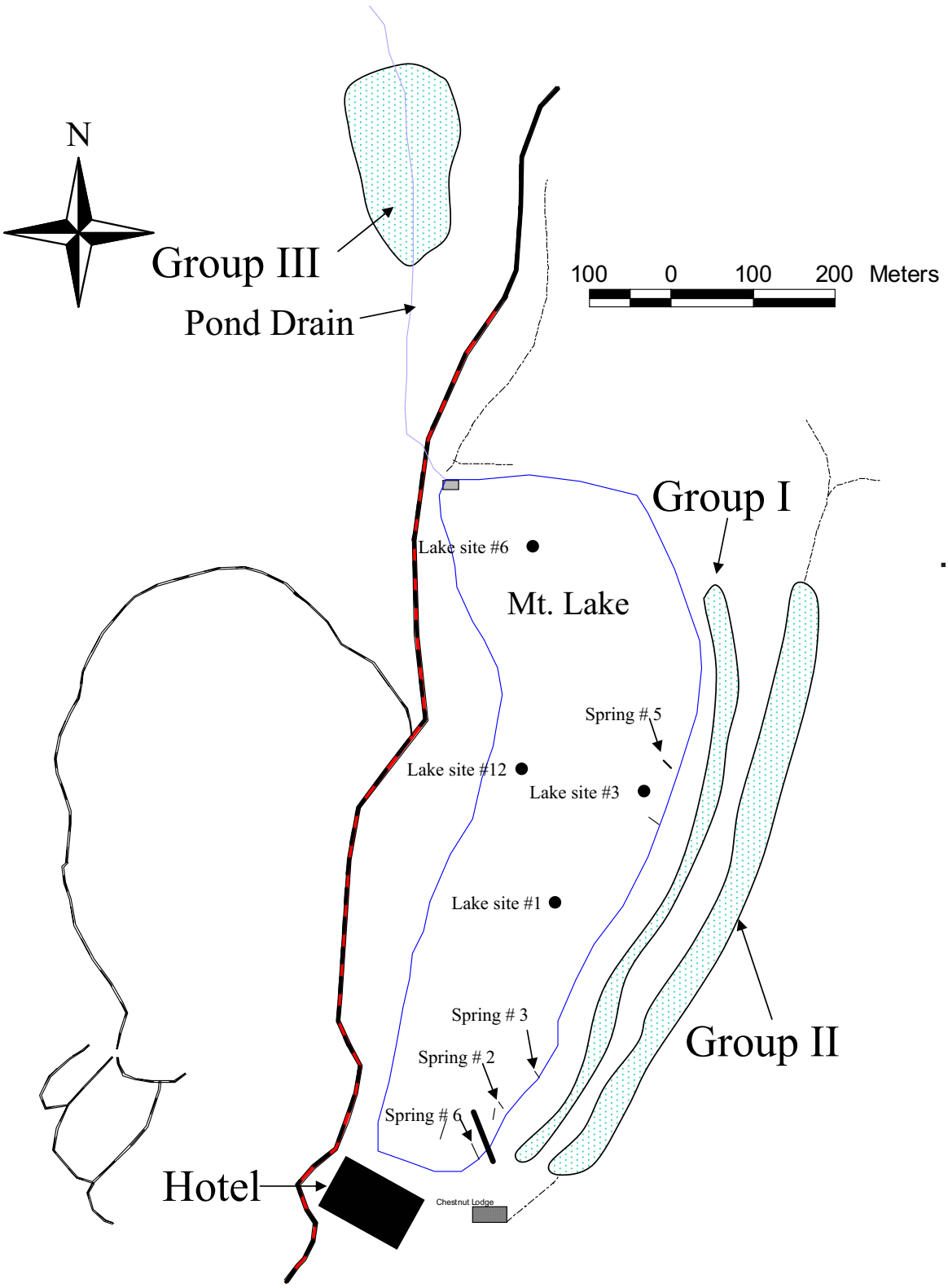

Figure 1. Sampling sites.

Unlike the health of Group I, there was no difference in tree health between the treated and untreated trees and no change in health over the three-year period (Table 4). This group of trees also had a lower density of HWA than Group I in 2002, and this may have resulted in less stress on these trees. No treated or untreated trees have died in this group.

GROUP III.

Eleven weeks (July 9, 2002) after the first treatment (Table 5, Figure 1) the treated trees had 66% fewer HWA (0.59/cm) than untreated trees (1.73/cm). From April 2003 to April 2004, no differences in HWA density occurred. However, in June 2004 there were 87% fewer HWA on the treated trees (0.004 HWA / cm) compared with untreated trees (0.031 HWA / cm). Health of the treated and untreated trees improved from 2002 to 2003, but then declined in 2004 to the levels found in 2002 (Table 6).

MIGRATION OF MERIT

One month after the first soil treatment imidacloprid was found at 3.6 and 1.6 ppb in samples #6 and #12 (Figure 1), respectively (Table 7). No imidacloprid was found in lake water samples #1 and #3. After soil treatments in 2002, no imidacloprid was detected. While imidacloprid was not detected in the lake water three weeks after the 2003 soil injection, it was detected in the spring water.

Three months after this treatment trace amounts were found in the lake water and measurable amounts were found in the spring water. Measurable and trace amounts were also found in the lake and spring water in 2004. The soil at Mt. Lake is very porous and rocky and likely allowed for the migration of imidacloprid into the springs and lake. When soil injections were made, loose rock was often contacted. Soil injections in very rocky soil such as this may not be appropriate due to the potential migration of imidacloprid.

IMPACT ON NONTARGET BENTHIC SPECIES

The number of invertebrates did not change from 2001 to 2003 (Figure 1, Table 8). Although, imidacloprid was found in the spring water in April 2003 (Table 7) at a concentration up to 0.5 ppb, it did not appear to impact the invertebrate population. No sampling was done after 2003 due to the rise in the lake level, so the impact of the higher concentrations of imidacloprid found in 2004 could not be determined. The closest trees to the lake that were soil injected were approximately 50 m. However, many underground springs occur in this area, and it is likely that imidacloprid could travel into the springs and lake through this route.

The LC50 for trout, daphnia, and algae is 211,000, 85,000, and 10,000 ppb, respectively (Extoxnet 2005). The levels of imidacloprid in the lake water were well below detrimental concentrations for these groups of organisms. However, caution must be used when applying imidacloprid in rocky soils near water due to migration protential.

Table 1. Mean number of HWA per cm on soil injected imidacloprid treated and untreated hemlock trees in Group I at Mt. Lake.

	# HWA/cm						
	Treated		Untreated		*t* statistics		
Date	**n**	***X* ± SD**	**n**	***X* ± SD**	***t***	**df**	***P***
1st treatment April 7, 2001							
April 11, 2001	15	2.78±1.65	15	2.78±1.87	-0.008	28	0.99
June 25, 2001	15	3.09±1.14	15	3.52±1.55	-0.846	28	0.40
Feb. 15, 2002	15	1.97±1.35	15	1.49±1.16	1.032	28	0.31
2nd treatment April 6, 2002							
June 18, 2002	15	2.13±1.14	15	3.29±1.16	-2.769	28	0.01
April 15, 2003	15	0.01±0.02	15	0.03±0.02	-0.873	28	0.39
June 24, 2003	15	0.003±0.010	15	0.038±0.136	-0.997	28	0.34
Jan. 22, 2004	15	0.001±0.002	15	0.074±0.187	-1.533	28	0.14
June 23, 2004	15	0.0	15	0.048±0.144	-1.287	28	0.21

Table 2. Tree health index for soil injected imidacloprid treated and untreated hemlock trees in Group I at Mt. Lake.

	Tree Health Index						
	Treated		Untreated		*t* statistics		
Date	**n**	***X* ± SD**	**n**	***X* ± SD**	***t***	**df**	***P***
1st treatment April 7, 2001							
2001	15	78±4 a[1]	15	74±7 a	-1.94	28	0.06
2nd treatment April 6, 2002							
2002	15	62±7 b	15	58±6 b	1.60	28	0.12
2003	15	51±7 c	15	44±6 c	2.60	28	0.01
2004	15	52±20 c	15	20±22 d	4.28	28	0.001

[1]Means followed by the same letter in the column are not significantly different at P = 0.05,Tukey-Kramer HSD test.

Table 3. Mean number of HWA per cm on soil injected imidacloprid treated and untreated hemlock trees in Group II at Mt. Lake.

	# HWA/cm						
	Treated		Untreated		*t* statistics		
Date	**n**	***X* ± SD**	**n**	***X* ± SD**	***t***	**df**	***P***
1st treatment April 6, 2002							
July 3, 2002	15	1.14±0.87	15	2.39±0.92	-3.820	28	0.001
2nd treatment April 4, 2003							
March 25, 2003	15	0.006±0.021	15	0.064±0.141	-1.565	28	0.129
June 24, 2003	15	0.012±0.041	15	0.028±0.107	-0.904	28	0.381
Feb. 19, 2004	15	0.008±0.018	15	0.016±0.021	-1.118	28	0.273
June 23, 2004	15	0.005±0.017	15	0.069±0.075	-3.241	28	0.003

Table 4. Tree health index values for soil injected imidacloprid treated and untreated hemlock Trees in Group II at Mt. Lake.

	Tree Health Index						
	Treated		Untreated		*t* statistics		
Date	**n**	***X* ± SD**	**n**	***X* ± SD**	***t***	**df**	***P***
1st treatment April 6, 2002							
2002	15	63±4 a[1]	15	63±6 a	-0.26	28	0.79
2nd treatment April 4, 2003							
2003	15	56±7 a	15	55±7 a	0.34	28	0.74
2004	15	54±2 a	15	54±2 a	0.067	28	0.95

[1]Means followed by the same letter in the column are not significantly different at P = 0.05,Tukey-Kramer HSD test.

Table 5. Mean number of HWA per cm on Mauget stem injected imidacloprid treated and untreated hemlock trees in Group III at Mt. Lake.

	# HWA/cm						
	Treated		Untreated		*t* statistics		
Date	**n**	***X* ± SD**	**n**	***X* ± SD**	***t***	**df**	***P***
1st treatment April 23, 2002							
July 9, 2002	10	0.59±0.42	10	1.73±0.89	-3.65	18	0.002
2nd treatment April 16, 2003							
April 16, 2003	10	0.015±0.04	10	0.019±0.03	-0.291	18	0.774
July 8, 2003	10	0	10	0.003±0.009	-1.00	9	0.343
April 6, 2004	9	0.001±0.003	9	0.005±0.007	-1.639	16	0.121
June 29, 2004	10	0.004±0.007	10	0.031±0.036	-2.319	18	0.032

Table 6. Tree health index for Mauget stem injected imidacloprid treated and untreated hemlock trees in Group III at Mt. Lake.

	Tree Health Index						
	Treated		Untreated		*t* statistics		
Date	**n**	***X* ± SD**	**n**	***X* ± SD**	***t***	**df**	***P***
1st treatment April 23, 2002							
2002	10	64±2 b[1]	10	64±4 b	-0.07	18	0.94
2nd treatment April 16, 2003`							
2003	10	73±3 a	10	72±4 a	0.84	18	0.41
2004	10	66±6 b	10	64±9 b	0.57	18	0.57

[1]Means followed by the same letter in the column are not significantly different at P = 0.05,Tukey-Kramer HSD test.

Table 7. Parts per billion (ppb) of imidacloprid found in water samples at Mt. Lake.

Date collected	Lake Site#	Imidacloprid ppb	Spring Site#	Imidacloprid ppb
		Soil treatment on April 7, 2001		
April 10, 2001	6	0		
	12	0		
May 7, 2001	1	0		
	3	0		
	6	3.6		
	12	1.6		
March 14, 2002	1	0		
	3	0		
	6	0		
	12	0		
		Soil treatment on April 6, 2002		
June 27, 2002	1	0		
	3	0		
	6	0		
	12	0		
		Soil treatment on April 4, 2003		
April 22, 2003	1	0	2	0.46
	3	0	3	0
	6	0	5	0
	12	0	6	0.26
July 8, 2003	1	trace[1]	2	0
	3	trace	3	trace
	6	0	5	0.069
	12	trace	6	0
May 11, 2004	1	trace	2	0
	3	trace	3	trace
	6	trace	5	NT[2]
	12	0	6	trace
		Soil treatment on Sept. 30, 2004		
Dec. 12, 2004	1	1.7	2	0
	3	0	3	3.5
	6	0	5	3.3
	12	0	6	0.7

[1]"Trace" indicates that imidacloprid was present but at levels below 0.02 ppb.
[2]NT = not tested.

Table 8. The mean number of invertebrates in springs sampled around the perimeter of Mt.Lake.

Sample Date	Number of Springs	# Invertebrates per Stone $X \pm SD$
April 17, 2001	6	0.43±0.74 a[1]
July 17, 2001	4	0.74±0.36 a
March 27, 2002	7	2.29±5.02 a
June 27, 2002	4	2.62±1.75 a
April 22, 2003	7	3.33±2.89 a

[1]Means followed by the same letter are not significantly different at P = 0.05, Tukey-Kramer HSD test.

CONCLUSIONS

Soil and stem injections of imidacloprid significantly reduced the density of HWA, from 35% to 93%. Tree health did not improve three years after the first treatment of imidacloprid, but did not decline as rapidly as it did in untreated trees, and the treatments have prevented or delayed the death of these trees. Tree Groups I, II, and III were not located in the same area and consequently were not subject to the same biotic and abiotic factors due to the differences in topography and microhabitat. Conclusions on the efficacy of imidacloprid on HWA among these three groups may not be valid. However, all groups of trees (soil injected and stem injected) have similar health indices and both treatment methods appear to be providing a similar protection from the impact of HWA.

Although low levels of imidacloprid were present in lake and spring water, the number of invertebrates did not change over the course of this study and did not appear to be impacted by imidacloprid. However, caution must be used when applying imidacloprid near waterways due to migration potential. More research is needed to determine more definitively a safe distance for treating trees near water, especially in porous rocky soil.

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REFERENCES

Cowles, R.S. and C.A.S.-J. Cheah. 2002. Foliar sprays for control of hemlock woolly adelgid, 2001, Arthropod Management Tests 27:G48.

Extoxnet. 2005. Extension toxicology network. http://extoxnet.orst.edu/.

McClure, M.S. 1991. Density-dependent feedback and population cycles in *Adelges tsugae* (Homoptera: Adelgidae) on *Tsuga canadensis*. *Ann. Entomol.* 20:258-264.

Silcox, C.A. 2002. Using imidacloprid to control hemlock woolly adelgid, *In* Rutgers NJ. Onken, B., R. Reardon, and J. Lashomb (Eds.), Proceedings: hemlock woolly adelgid in the Eastern United States Symposium, 5-7 Feb. 2002, USDA Forest Service. pp. 280–287.

SAS. 1989. SAS/STAT User's Guide, ver. 6, fourth ed. SAS Institute INC., Cary, North Carolina.

Steward, V.B., G. Braness, and S. Gill. 1998. Ornamental pest management using imidacloprid applied with Kioritz® soil injector. *J. of Arboric.* 24:344-346.

Steward, V.B. and T.A. Horner. 1994. Control of hemlock woolly adelgid using soil injections of systemic insecticides. J. of Arboric. 20:287-288.

Tatter, T.A., J.A. Dotson, M.S. Ruizzo, and V.B. Steward. 1998. Translocation of imidacloprid in three tree species when trunk- and soil-injected. *J. of Arboric.* 24:54-56.

Webb, R.E., J.R. Frank, and M.J. Raupp. 2003. Eastern hemlock recovery from hemlock woolly adelgid damage following imidacloprid therapy. *J. of Arboric.* 29:298-301.