DRAFT REPORT

Terrestrial Gastropods as Focal Species for Monitoring the Ecological Effects of Variable-retention Logging Practices

Progress Report for 2005 Field Season

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Cover photos: Variable-retention logging at the Tsitika (left) and Horseshoe Lake (right) experimental sites showing group-retention and dispersed logging methods. Inset: Northwest Hesperian (Vespericola columbianus) on artificial cover-object used for sampling gastropods.
EXECUTIVE SUMMARY

Terrestrial gastropods (slugs and land snails) were selected as a focal group for examining the effects of variable-retention (VR) logging practices on forest ecosystems within the Adaptive Management Program of Cascadia Forest Products (formerly Weyerhaeuser Company Limited). From 2001 to 2003, we conducted pre-disturbance surveys at six experimental sites, each consisting of an uncut control, clearcut, and three variable-retention (VR) logging treatments. This report presents the results of surveys conducted 3.5 – 4 years after logging at two of these sites in 2005: Tsitika (R917) on northern Vancouver Island (trees retained in groups) and Horseshoe Lake (R949), near Powell River on the mainland coast of British Columbia (trees retained throughout the logged areas in a dispersed pattern).

At Tsitika, we detected 12 species of gastropods, consisting of three species of slugs and nine snails. Two of 7 gastropods tested showed effects consistent with logging in comparisons of pre- and post-logging data of relative abundance, based on sampling with artificial cover-objects. These gastropods were *Pristiloma* species (mostly *P. stearnsii*) and *Striatura pugetensis*, small snails that are associated with moist forest floor conditions. There were no significant differences among the three VR-treatments, but the clearcut tended to have lowest abundance of both species. The post-logging data show that many gastropods at this cool, moist site (CWHvm1 biogeoclimatic variant) were relatively tolerant and continued to persist within the logged areas, including the VR-groups and the clearcut.

At Horseshoe Lake, we detected 18 species of gastropods, consisting of three species of slugs and 15 species of snails. Small litter-dwelling snails were particularly well represented. Ten of 13 species or groups tested showed significant treatment effects in pre- and post-logging comparisons. The effects for 7 of 9 species and for all small snails combined were consistent with adverse effects of logging, while effects for two snails of the family Polygyridae were inconclusive and showed disproportionate increases in some VR-treatments (*Vespericola columbianus* and *Cryptomastix germana*). Gastropods with effects consistent with logging included 7 species of small litter-dwelling snails (*Nesovitrea binneyana*, *Striatura pugetensis*, *Planogyra clappi*, *Pristiloma* species, *Punctum randolphii*, and *Vertigo* species) and a large carnivorous snail (*Haplotrema vancouverense*). The VR-dispersed treatment with 30% retention level was statistically indistinguishable from the control for two sensitive gastropods (*Pristiloma* spp and *H. vancouverense*) and for all small snails combined; three additional species showed a trend towards greater relative abundance in the 30% dispersed treatment when compared to the other logging treatments (10% and 5% retention level and clearcut). The post-logging data show that many gastropods at this relatively warm, dry site (CWHdm biogeoclimatic variant) were adversely affected by logging and hence provided good focal species for adaptive management.

Small snails (with shell diameter < 5 mm) extracted from litter samples indicated that densities had increased across the treatments from 2001 to 2005 at the Tsitika site,
probably due to natural causes, but decreased precipitously across the logged
treatments at the Horseshoe Lake site. Results of pre-post comparisons for many
individual species showed trends similar to data obtained from artificial cover-objects,
but all were statistically non-significant due to low sample sizes and high variability
among plots (there were 10 times more samples for artificial cover-object data than for
litter sample data at both sites).

We detected relatively few effects attributable to logging at the Tsitika Experimental
Site, whereas decreased abundance of many species at the Horseshoe Lake
Experimental Site was consistent with adverse effects of logging. The two sites were
very different in terms of habitat and characteristics of gastropod faunas, and responses
of gastropods to logging most likely reflected these differences. Due to high densities
and diversity of species, the Horseshoe Lake site provided an excellent opportunity to
examine effects of logging on small litter-dwelling snails. Post-logging surveys at the
four remaining experimental sites to be conducted in 2006 and 2007 will help clarify the
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1.0 INTRODUCTION

Terrestrial gastropods (slugs and land snails) were selected as a focal group for examining the effects of variable-retention (VR) logging practices in forest ecosystems as part of Cascadia Forest Product’s (originally Weyerhaeuser’s) Adaptive Management Program (Bunnell et al. 2003). These organisms were included because of their sensitivity to changes to forest floor conditions associated with logging and their sedentary habits, which preclude escape from unfavourable conditions. As a result, gastropod faunas are likely to reflect the disturbance history of forest stands (Strayer et al. 1986, Prezio et al. 1999). One goal of VR-logging is to retain some attributes of old-growth forest in logged areas, in an attempt to retain biodiversity in lands managed for forestry. Gastropods may benefit from the retention of old-growth attributes in logged areas as retention patches may act as refuges for sensitive species and aid subsequent dispersal to the logged matrix as the forest regenerates.

This project is a continuation of a pilot study initiated in the autumn of 1999. Initial studies, from 1999 to 2001, focused on characterizing gastropod faunas of different forest types, developing sampling methodologies, and investigating the sensitivity of different species to logging at operational VR-sites (Ovaska and Sopuck 2000, 2001, 2002). In 2001 work began at experimental sites with the objective of comparing the effectiveness of different types of VR-treatments and clearcutting on maintaining patterns of species diversity and abundance of gastropods on the forest floor. From 2001 to 2003, we completed intensive pre-disturbance sampling at six experimental sites (3 on Vancouver Island, 2 on coastal mainland, and 1 in Queen Charlotte Islands; Ovaska and Sopuck 2003, 2004, 2005). These pre-disturbance data are to be compared with data collected after logging on the same plots. Such an experimental approach provides a powerful method for examining causal effects of different logging treatments by taking into account pre-existing differences in gastropod populations due to habitat.

This progress report presents the results of post-logging surveys and comparisons with pre-logging data at two of the six experimental sites, Tsitika on Vancouver Island and Horseshoe Lake near Powell River on the mainland coast. Additional post-logging surveys will be conducted at the remaining four sites in 2006 and 2007.

2.0 STUDY AREA AND METHODS

2.1 Study Sites

During the 2005 field season, surveys for gastropods were conducted 3.5 - 4.0 years after logging at two experimental sites: (1) in the Tsitika Valley (group retention completed in fall 2001); and (2) adjacent to Horseshoe Lake near Powell River on the coastal mainland (dispersed retention completed from fall 2001 to spring 2002). The Tsitika site (R917) is located in the CWHvm1 biogeoclimatic zone at elevations ranging from 350 – 500 m asl. The forest cover consisted of old-growth coniferous forest (>180 years old) dominated by Western Hemlock, Western Redcedar, and Amabilis Fir.
Common understory shrubs included Huckleberries (*Vaccinium parvifolium*, *V. ovatum*), Salal (*Gaultheria shallon*), Devil’s Club (*Oplopanax horridus*), and False Azalea (*Menziesia ferruginea*). Moss cover was extensive, and coarse woody debris, including large-diameter logs and branches, was abundant.

The Horseshoe Lake site (R949) is in the CWHdm zone at elevations ranging from 175 – 250 m asl and is considerably drier with more productive soils and milder climate than the Tsitika site. The forest cover consisted of naturally regenerated, mature second growth with trees about 100 years old. Dominant trees were Douglas-fir, Western Hemlock, Western Redcedar, and Red Alder. A few large Bigleaf Maples occurred at lower elevations. Dominant shrubs were Salal, Oregon Grape, Red Huckleberry, and Salmonberry. Sword Ferns were common in moist areas.

### 2.2 Study Design

Gastropod sampling plots were set at 5 treatment areas before logging and were sampled both before and after logging. The treatments were as follows:

**Tsitika:** Clearcut; VR-group (10%); VR-group (20%); VR-group (30%); Control (old-growth); the retention level included both groups and riparian buffer strips in each treatment; only groups were sampled for gastropods. In 2002, a major windstorm resulted in extensive blow-down of old-growth trees in the retention groups and riparian buffer strips at the Tsitika Site. The retention level in the three VR-treatments was reduced by 65-80% after the storm based on the number of standing trees, thus reducing canopy coverage in the groups (canopy coverage was not measured). However, the layers of fallen and leaning timber in the groups provided some shading of the forest floor and increased the amount of coarse woody debris used for shelter by gastropods.

**Horseshoe Lake:** Clearcut; VR-dispersed (5% retention); VR-dispersed (10% retention); VR-dispersed (30% retention); Control (mature second growth)

The number of plots per treatment was four at Tsitika and three at the Horseshoe Lake site. In the VR- treatment areas, we placed our plots at locations selected by the Weyerhaeuser’s (now Cascadia’s) structural monitoring team for surveys of vegetation and other structural features. For the fourth plot at Tsitika, we randomly selected an additional site. There were six structural monitoring plots within the control and clearcut treatments. We randomly selected plots for gastropod sampling. Within the VR-group treatments at Tsitika, we placed gastropod plots within the designated tree patches, rather than within the matrix surrounding the groups.

Each gastropod sampling plot consisted of ten sampling stations, distributed 10 m apart along two perpendicular, randomly oriented transect lines. Hence, there were 40 stations (4 plots) per treatment area at Tsitika for a total of 200 stations, and 30 stations (3 plots) per treatment area at Horseshoe Lake for a total of 150 stations.
At Tsitika, we conducted three pre-logging surveys in May – June, 2001 and three post-logging surveys in May – June 2005. Logging took place in the summer and autumn of 2001. At Horseshoe Lake, we conducted two pre-logging surveys in September – October, 2001 and three post-logging surveys in September – October 2005. Logging took place between the fall of 2001 and spring of 2002. See Appendix A for details of the sampling design and timing of surveys at the two experimental sites. Maps of the experimental design for the sites, showing the placement of gastropod plots, are shown in Figures 1 and 2.

2.3 Survey Methods
We used two main methods to sample gastropods at the experimental sites: artificial cover-objects and litter sampling. Pilot studies in 1999 – 2001 deemed these methods most appropriate for measuring relative abundance (Ovaska and Sopuck 2000, 2001, 2002).

2.3.1 Artificial cover-objects
Artificial cover-objects consisted of sheets of corrugated cardboard that other studies (Hawkins et al. 1998) and our own previous studies had determined were effective for sampling a variety of terrestrial gastropods that use the structures for shelter. The cardboards mimic natural cover-objects, such as decaying bark and coarse woody debris that frequently fall on the forest floor. The sheets are laid flush with the ground, and allowed to weather and accumulate moisture for at least two weeks. The cover-objects are then inspected for gastropods that adhere to the surfaces of the board or use the ground interface. The advantages of this method are ease of sampling, minimal observer bias, and little disturbance to the surrounding habitat, allowing repeated surveys of sensitive habitats such as small retention groups.

Our design for the cover-object evolved over the study, hence the type and number of cover-objects used at the six experimental sites differ somewhat. Initially, in 2001, we used two small (1’ x 1’), layered covers and one large (2’ by 2’) single sheet at Tsitika and Horseshoe Lake at each sampling station. Subsequently, in 2005, we used only small cardboard covers, four per station, because small covers were found to be more effective than large cardboards, resulting in larger sample sizes (Ovaska and Sopuck 2002, 2003). The small covers (1’X1’) used for post-logging surveys at Tsitika and Horseshoe Lake consisted of two cardboard sheets stapled together along one side, resulting in four sampling surfaces (top, bottom, and two in-between). The bottom sheet had a wavy, corrugated surface on both sides, created by stapling two single faced corrugated sheets together. The exposed corrugated surfaces were designed to enhance the substrate for the attachment of small snails.
Figure 1. Photo mosaic of the experimental layout at the Tsitika site.
Figure 2. Photo mosaic of the experimental layout at the Horseshoe Lake site.
2.3.2 Litter samples
To obtain an additional estimate of the abundance of small snails, we collected litter samples at the sampling stations for subsequent analysis in the laboratory. This method is very effective for sampling small (with adult shell diameter < 5 mm) forest floor snails and has been used successfully in previous studies in British Columbia (Cameron 1986).

We collected samples of litter next to artificial cover-object stations using a small trowel. To standardize the amount and increase the variety of litter sampled, we sub-divided a 1 m x 1 m area into quarters and took a sample from the centre of each section for a total of 0.5 litres of litter at each station, resulting in a total of 5 liters per plot (2.5 l per plot was deemed adequate at the Horseshoe Lake site, where small snails were very abundant during the pre-logging period). The objective was to sample a profile of the top layer of the forest floor to a depth of about 10 cm; most gastropods are found within the top layer (Hawkins et al. 1998).

In the laboratory, we first froze the samples to stop any biological activity and then air-dried them. We passed each dried sample through a set of three sieves (mesh diameters: 4.75 mm, 2.0 mm, and 0.5 mm; USA standard testing sieves 4, 10, and 15) and hand-sorted through the residues under a magnifier-lamp (11.5 cm diameter, 3 x magnification lens encircled by a fluorescent light). We collected all snails found for microscopic examination. Identification of gastropods was done using descriptions in Pilsbry (1940, 1948) and Forsyth (2004).

2.4 Data Handling and Analyses
We used Microsoft Excel (Version 2000) spreadsheets and data analysis tools to summarize data and prepare figures. Statistical analyses were performed using the statistical package Jmp In (Version 3.2.1, 1989–1997, SAS Institute Inc.). To examine differences between pre- and post-logging periods, we used a split plot design and multivariate analysis of variance (MANOVA) to compare relative abundance, species diversity, and species richness of gastropods. Relative abundance of individual species or grouping of species was measured as (a) number of animals per artificial cover-object (ACO) station per survey (ACO data) or (b) mean number of animals per 1 liter of forest litter per plot (litter sample data). In analysis of the ACO data, there were 40 ACO stations in each treatment at the Tsitika site (3 pre-logging and 3 post-logging surveys; total of 240 data points per treatment) and 30 at the Horseshoe Lake site (2 pre-logging and 3 post-logging surveys; total of 150 data points per treatment). In analysis of the litter sample data, there were 4 samples per treatment at the Tsitika site and 3 at the Horseshoe Lake site, 1 sample per plot. In the MANOVA models, the effect variables were treatment and plot for the ACO data and treatment for the litter sample data, species diversity, and species richness measures.

To obtain a measure of species diversity, we used the Shannon-Wiener index of heterogeneity (Krebs 2003). This index is particularly sensitive to rare species in a data set. We calculated Shannon’s H’ for each plot during pre-logging and post-logging period from ACO data combined for 3 surveys during each period. These values were
then used as response variables in the analysis of variance models. For species richness, we used the total number of species found during three surveys during the pre- and post-logging periods.

The probability of finding a significant effect by chance increases with the number of comparisons performed (i.e., increased Type I error or falsely detecting a significant effect where one does not exist). Therefore, for each set of comparisons, we used the sequential Bonferroni-correction to calculate experiment-wide alpha (Rice 1989). The 1\textsuperscript{st} significant probability is calculated as \( \alpha/k \), the 2\textsuperscript{nd} as \( \alpha/(k-1) \), the 3\textsuperscript{rd} as \( \alpha/(k-3) \) and so on, where \( \alpha \) represents experiment-wide level of significance and \( k \) the number of parameters or comparisons made. For comparisons where more than 5 species were tested individually, we set experiment-wide \( \alpha = 0.1 \) to avoid a Type II error (i.e., failing to detect a significant effect where one exists). For other comparisons, we used experiment-wide \( \alpha = 0.05 \). At Tsitika, we tested effects of logging on the relative abundance of 10 species or groupings. Therefore, the 1\textsuperscript{st} significant probability value for individual species was 0.010, the 2\textsuperscript{nd} 0.011, the 3\textsuperscript{rd} 0.0125, the 4\textsuperscript{th} 0.014 and so on. At Horseshoe Lake, there were 13 comparisons. Therefore, the 1\textsuperscript{st} significant probability value for individual species was 0.0076, the 2\textsuperscript{nd} 0.0083, the 3\textsuperscript{rd} 0.009, the 4\textsuperscript{th} 0.01, and so on.

\section*{3.0 RESULTS AND DISCUSSION}

\subsection*{3.1 Tsitika Experimental Site (R917)}

\subsubsection*{3.1.1. Overview of species found}

In total, we detected 12 species of gastropods at this site, consisting of three species of slugs and nine snails (Table 1). The snails represented three species of large snails (\textit{Vespericola columbianus}, \textit{Haplotrema vancouverense}, \textit{Ancotrema} species) and six species of small litter-dwelling snails with adult shell diameter less than 5 mm (remaining snail species in Table 1). Both species richness and abundance were relatively low at this site (Ovaska and Sopuck 2005). For most species, sample sizes were larger in 2005 than in 2001. This increase represents a combination of a sampling artifact (more effective artificial cover-object design was used in 2005) and increased overall abundance of small litter snails, as determined from litter sampling, due to weather or natural multi-year fluctuations in population sizes.
Table 1. Summary of gastropods found at the Tsitika experimental site during pre-logging and post-logging survey periods in May - June 2001 and 2005, respectively. There were 200 sampling stations; 100 l of litter was examined in 2001 and 2005. See Appendix A for a breakdown of numbers of gastropods by treatment. Codes are used in Appendices.

<table>
<thead>
<tr>
<th>Species</th>
<th>CODE</th>
<th>Pre-logging surveys, 2001</th>
<th>Post-logging surveys, 2005</th>
</tr>
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<td></td>
<td></td>
<td>Artificial cover-objects</td>
<td>Litter samples: Live (dead)</td>
</tr>
<tr>
<td>Slugs:</td>
<td></td>
<td></td>
<td></td>
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<tr>
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<td></td>
<td></td>
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</tr>
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<tr>
<td>Western Flat-whorl, <em>Planogyra clappi</em></td>
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<td>VER spp</td>
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<td>10 (19)</td>
</tr>
</tbody>
</table>

<sup>1</sup>Mostly *P. stearnsii*; small juveniles could not identified to species reliably

<sup>2</sup>Mostly *V. columbianus* and juveniles not identified to species; 3 very small unidentified juvenile Vertiginidae (Vertiginidae) excluded
3.1.2 Relative abundance (ACO data)

Adequate sample sizes for statistical comparisons existed for seven species of gastropods. Two of the seven species showed significant treatment effects in comparisons of relative abundance between pre- and post-logging periods: *Pristiloma* snails and *Striatura pugetensis* (Table 2; see Appendix A for a summary of the data by plot). Both effects were consistent with logging and showed a similar pattern (Figure 3): abundance was greatest in the control and lower in the logging treatments. VR-groups in all treatments tended to support more snails of both species than the clearcut, but in pair-wise comparisons the only statistically significant difference was between the control and all other treatments after logging (Tukey-Kramer HSD test, $\alpha < 0.05$). Both *Pristiloma* species and *S. pugetensis* are small litter-dwelling snails associated with moist forest floor conditions. *Pristiloma stearnsii*, which formed the bulk of the *Pristiloma* samples in Tsitika, is frequently associated with coarse woody debris (Ovaska and Sopuck 2000).

There were no significant differences between pre- and post-logging periods in relative abundance of five species of gastropods (Table 2, Figure 3). However, sample sizes for *H. vancouverense*, suspected to be good indicator due to its moisture requirements, were low. Insufficient numbers of observations existed for four additional gastropods (*Prophysaon vanattae, Ancotrema species, Columella edentula, Planogyrca clappi*). When species were grouped together into slugs and small snails, there were no significant treatment effects for either group (Table 2).

There was a significant plot effect for two gastropods, the slug *P. foliolatum* and *Vertigo* snails, indicating that their abundance showed a different pattern among plots during 2005 surveys when compared to 2001 surveys. Abundance of *P. foliolatum* had increased disproportionately in some of the VR-groups post-logging, particularly in Plot 4 in the 20% treatment (Tukey-Kramer HSD test, $\alpha < 0.05$). This group was anchored on a small wetland supporting Skunk Cabbage and other forage plants of these slugs, which may have concentrated in this and other similar groups after the surrounding matrix was logged.

To illustrate patterns of abundance during pre- and post-logging periods, we used the average of three surveys for each data point in Figure 3. This simplification was done to clarify the presentation of the data; note that results of each survey were included as separate data points in statistical analyses.
Table 2. Test statistics for comparison of relative abundance (number per artificial cover-object station) of individual species and groupings of gastropods between pre- and post-logging survey periods at the Tsitika experimental site (Manova). Data from artificial cover-objects. Highlighted cells indicate significant effects. Pre-logging period – 2001 (3 surveys), post-logging period - 2005 (3 surveys).

<table>
<thead>
<tr>
<th>Species or group</th>
<th>Treatment</th>
<th>Plot</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Wilks' lambda</td>
<td>F(_{4,180})</td>
</tr>
<tr>
<td><strong>Slugs:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Ariolimax columbianus</em></td>
<td>0.9580</td>
<td>1.9711</td>
</tr>
<tr>
<td><em>Prophysaon foliolatum</em></td>
<td>0.9341</td>
<td>3.1747</td>
</tr>
<tr>
<td><strong>Snails:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Haplotrema vancouverense</em></td>
<td>0.9834</td>
<td>0.7578</td>
</tr>
<tr>
<td><em>Pristiloma species</em></td>
<td>0.7967</td>
<td>11.4834</td>
</tr>
<tr>
<td><em>Punctum randolphii</em></td>
<td>0.9897</td>
<td>0.4672</td>
</tr>
<tr>
<td><em>Striatura pugetensis</em></td>
<td>0.9244</td>
<td>3.6808</td>
</tr>
<tr>
<td><em>Vertigo species</em></td>
<td>0.9594</td>
<td>1.9042</td>
</tr>
<tr>
<td><em>Vespericola columbianus</em></td>
<td>0.9742</td>
<td>1.1935</td>
</tr>
<tr>
<td><strong>Guilds:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Slugs (3 spp. combined)</td>
<td>0.9500</td>
<td>2.3683</td>
</tr>
<tr>
<td>Small snails (6 spp. combined)</td>
<td>0.9478</td>
<td>2.4780</td>
</tr>
</tbody>
</table>

1 Sequential Bonferroni correction was applied to achieve experiment-wide alpha of 0.1
Figure 3. Relative abundance of gastropod species in different treatment areas before and after logging at the Tsitika Experimental Site, sampled with artificial cover-objects. Pre-logging surveys: May–June 2001; Post-logging surveys: May–June 2005, 4 years after logging; relative abundance: # of animals/sampling station averaged across 3 surveys in both 2001 and 2005; n = 40 stations/treatment area.

Pacific Banana Slug
(Ariolimax columbianus)

Yellow-bordered Taildropper
(Prophysaon foliolatum)

Robust Lancetooth
(Haplotrema vancouverensis)
Figure 3 (continued). Relative abundance of gastropod species in different treatment areas before and after logging at the Tsitika Experimental Site, sampled with artificial cover-objects.

**Northwest Hesperian**  
*Vespericola columbianus*

**Tightcoil snails**  
*Pristiloma* species

**Conical Spot**  
*Punctum randolphii*
Figure 3 (continued). Relative abundance of gastropod species in different treatment areas before and after logging at the Tsitika Experimental Site, sampled with artificial cover-objects.

### Northwest Striate
*(Striatura pugetensis)*

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Mean #/ACO stn</th>
<th>Pre-logging</th>
<th>Post-logging</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clearcut</td>
<td></td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>VR-Group-10%</td>
<td></td>
<td>0.1</td>
<td>0.2</td>
</tr>
<tr>
<td>VR-Group-20%</td>
<td></td>
<td>0.2</td>
<td>0.3</td>
</tr>
<tr>
<td>VR-Group-30%</td>
<td></td>
<td>0.3</td>
<td>0.4</td>
</tr>
<tr>
<td>Control</td>
<td></td>
<td>0.4</td>
<td>0.5</td>
</tr>
</tbody>
</table>

$P = 0.007$

### Vertigo snails
*(Vertigo species)*

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Mean #/ACO stn</th>
<th>Pre-logging</th>
<th>Post-logging</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clearcut</td>
<td></td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>VR-Group-10%</td>
<td></td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>VR-Group-20%</td>
<td></td>
<td>0.1</td>
<td>0.2</td>
</tr>
<tr>
<td>VR-Group-30%</td>
<td></td>
<td>0.3</td>
<td>0.4</td>
</tr>
<tr>
<td>Control</td>
<td></td>
<td>0.4</td>
<td>0.5</td>
</tr>
</tbody>
</table>
Figure 3 (continued). Relative abundance of gastropod species in different treatment areas before and after logging at the Tsitika Experimental Site, sampled with artificial cover-objects.

### All slugs
(3 species combined)

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Pre-logging</th>
<th>Post-logging</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clearcut</td>
<td></td>
<td></td>
</tr>
<tr>
<td>VR-Group-10%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>VR-Group-20%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>VR-Group-30%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Control</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### All small snails
(6 species combined)

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Pre-logging</th>
<th>Post-logging</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clearcut</td>
<td></td>
<td></td>
</tr>
<tr>
<td>VR-Group-10%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>VR-Group-20%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>VR-Group-30%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Control</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
3.1.3 Relative abundance (litter data)

The litter sample data showed no statistically significant treatment effects for any of the five species of small snails tested (Table 3; see Appendix B for data used in the analyses). Most species showed higher abundance across plots in 2005 than in 2001, irrespective of logging treatments (significant “time” effect in Table 3). This increase was particularly pronounced within the VR-groups but was highly variable among plots, resulting in a non-significant treatment effect (Figure 4). Interestingly, several small snails showed unusually high numbers in one of the clearcut plots (CC3), which was less than 30 m from a large stand of old growth forest on the north edge of the experimental site. The shading and movement of snails from the old growth forest may have contributed to the high numbers of snails at this plot. This plot was omitted from statistical analysis (Table 3).

Table 3. Test statistics for comparison of average density (#/liter/plot) of individual species and groupings of small snails between pre- and post-logging survey periods at the Tsitika experimental site (Manova for repeated measures). Data from litter samples. Highlighted cells indicate significant effects. Pre-logging period - 2001, post-logging period - 2005. Insufficient observations for comparisons existed for 1 additional species (Columella edentula).

<table>
<thead>
<tr>
<th>Species or group</th>
<th>Treatment</th>
<th>Time</th>
<th>Time x Treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Wilks' lambda</td>
<td>F</td>
<td>P</td>
</tr>
<tr>
<td>Planogya clappi</td>
<td>0.7379</td>
<td>1.2432</td>
<td>0.3377</td>
</tr>
<tr>
<td>Pristiloma species</td>
<td>0.7484</td>
<td>1.1767</td>
<td>0.3631</td>
</tr>
<tr>
<td>Punctatum randolphii</td>
<td>0.7342</td>
<td>1.2673</td>
<td>0.3289</td>
</tr>
<tr>
<td>Striatura pugetensis</td>
<td>0.7693</td>
<td>1.0497</td>
<td>0.4170</td>
</tr>
<tr>
<td>Vertigo species</td>
<td>0.6623</td>
<td>1.7850</td>
<td>0.1880</td>
</tr>
<tr>
<td>All small snails (combined)</td>
<td>0.7461</td>
<td>1.1912</td>
<td>0.3574</td>
</tr>
</tbody>
</table>

3.1.4 Species diversity and richness

Both species diversity and richness were similar across the treatments, and we detected no effects consistent with logging (Table 4; Figure 5; see Appendix C for data used in the analyses). The number of species per plot was greater in 2005 than in 2001 (significant “time” effect in Table 4), although the total number of species found across the surveys was similar. This increase was due to larger sample sizes obtained in 2005, resulting in more of the species present detected in each plot.

Table. 4. Test statistics for comparison of species diversity (Shannon’s H') and richness (number of species) of gastropods per plot between pre- and post-logging periods. Values calculated for each plot based on total numbers of animals caught during 3 surveys per season.

<table>
<thead>
<tr>
<th>Effect</th>
<th>A. Shannon’s H'</th>
<th>B. # of species</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Wilks' lambda</td>
<td>F</td>
</tr>
<tr>
<td>Treatment</td>
<td>0.7644</td>
<td>1.1559</td>
</tr>
<tr>
<td>Time</td>
<td>0.7499</td>
<td>5.0036</td>
</tr>
<tr>
<td>Treatment x Time</td>
<td>0.9542</td>
<td>0.1799</td>
</tr>
</tbody>
</table>
Figure 4. Density of small snails based on litter samples collected during pre-logging and post-logging periods at the Tsitika Experimental Site. Plot CC3 in clearcut treatment shown separately due to anomalous data points during post-logging surveys; the plot was only ca. 30 m from old growth edge. Per 1 liter of litter (total of 5 liters collected pre & post logging). Pre- and Post-logging for Clearcut exclude CC3 that was 30 m from old growth edge; Pre- and Post-logging (CC3) show value per liter for that plot.
Figure 4 (continued). Density of small snails based on litter samples collected during pre-logging and post-logging periods at the Tsitika Experimental Site.

(Striatura pugetensis)

Vertigo snails
(Vertigo spp)

All small snails
(6 species)
Figure 5. Comparison of species diversity (Shannon-Wiener index) and species richness (# of species detected per plot) of terrestrial gastropods among different logging treatments during pre- and post-logging periods at the Tsitika Experimental Site.

A. Tsitika: Species Diversity

B. Tsitika: Species richness
3.2 Horseshoe Lake Experimental Site (R949)

3.2.1 Overview of species found

In total, we detected 18 species of gastropods at this site, consisting of three species of slugs and 15 snails (Table 5). The slug *Arion rufus*, an exotic species, was found only during the post-logging period and may represent a recent, inadvertent introduction to the site. The snails consisted of four species of large snails (*Vespericola columbianus*, *Cryptomastix germana*, *Haplotrema vancouverense*, *Ancotrema* species) and 11 species of small litter-dwelling snails with adult shell diameter less than 5 mm (remaining snail species in Table 5). Both species richness and abundance were relatively high at this site; small snails, in particular, were well represented (Ovaska and Sopuck 2005). In contrast, slugs were relatively scarce.

Table 5. Summary of gastropods found at the Horseshoe Lake Experimental Site during pre-logging and post-logging survey periods in May - June 2001 and 2005, respectively. There were 150 sampling stations; 37.5 liters of forest litter was examined in 2001 and 75 liters in 2005. See Appendix A for a breakdown of numbers of gastropods by treatment. Codes are used in Appendices.

<table>
<thead>
<tr>
<th>Species</th>
<th>Code</th>
<th>Artificial cover-objects</th>
<th>Litter samples:</th>
<th>Artificial cover-objects</th>
<th>Litter samples:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Pre-logging surveys, 2001</td>
<td>Live (dead)</td>
<td>Post-logging surveys, 2005</td>
<td>Live (dead)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Slugs:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pacific Banana-slug, <em>Ariolimax columbianus</em></td>
<td>ARICO</td>
<td>41</td>
<td>NA</td>
<td>48</td>
<td>NA</td>
</tr>
<tr>
<td>Chocolate Arion, <em>Arion rufus</em> (introduced)</td>
<td>ARIRU</td>
<td>0</td>
<td>NA</td>
<td>15</td>
<td>NA</td>
</tr>
<tr>
<td>Scarletback Taildropper, <em>Prophysaon vanattae</em></td>
<td>PROVA</td>
<td>1</td>
<td>NA</td>
<td>15</td>
<td>NA</td>
</tr>
<tr>
<td>Snails:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lancetooth snails, <em>Ancotrema</em> spp.</td>
<td>ANC sp</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Pygmy Oregonian, <em>Cryptomastix germana</em></td>
<td>CRYGE</td>
<td>29</td>
<td>NA</td>
<td>139</td>
<td>NA</td>
</tr>
<tr>
<td>Robust Lancetooth, <em>Haplotrema vancouverense</em></td>
<td>HAPVA</td>
<td>106</td>
<td>NA</td>
<td>99</td>
<td>NA</td>
</tr>
<tr>
<td>Northwest Hesperian, <em>Vespericola columbianus</em></td>
<td>VESCO</td>
<td>39</td>
<td>NA</td>
<td>216</td>
<td>NA</td>
</tr>
<tr>
<td>Toothless Column, <em>Columella edentula</em></td>
<td>COLED</td>
<td>28</td>
<td>4 (10)</td>
<td>26</td>
<td>3 (2)</td>
</tr>
<tr>
<td>Brown Hive, <em>Euconulus fulvus</em></td>
<td>EUCFU</td>
<td>125</td>
<td>41 (8)</td>
<td>644</td>
<td>56 (28)</td>
</tr>
<tr>
<td>Blue Glass, <em>Nesovitrea binneyana</em></td>
<td>NESBI</td>
<td>126</td>
<td>83 (36)</td>
<td>162</td>
<td>120 (35)</td>
</tr>
<tr>
<td>Western Flat-whorl, <em>Planogyra clappi</em></td>
<td>443</td>
<td>354 (119)</td>
<td>288</td>
<td>59 (34)</td>
<td></td>
</tr>
<tr>
<td>Tightcoil snails, <em>Pristiloma stearnsii</em> &amp; <em>P. lansingii</em></td>
<td>PRI sp</td>
<td>241</td>
<td>132 (65)</td>
<td>470</td>
<td>122 (36)</td>
</tr>
<tr>
<td>Conical Spot, <em>Punctum randolphii</em></td>
<td>PUNRA</td>
<td>214</td>
<td>217 (125)</td>
<td>109</td>
<td>68 (26)</td>
</tr>
</tbody>
</table>
Pre-logging surveys, 2001 | Post-logging surveys, 2005
--- | ---
Artificial cover-objects | Artificial cover-objects | Litter samples: Live (dead) | Litter samples: Live (dead)
Northwest Striate, *Striatura pugetensis* | STRPU | 188 | 268 | 516 (355) | 403 (455)
Vertigo snails, *Vertigo* spp. | VER sp | 309 | 139 | 98 (47) | 31 (12)
Gloss snails, *Zonitoides arboreus* & *Z. nitidus* | ZON sp | 57 | 57 | 5 (1) | 48 (17)
TOTAL: | | 1947 | 2695 | 1450 (766) | 910 (645)

1. Mostly *P. stearnsii*; small juveniles could not identified to species reliably
2. Mostly *V. columbianus* and juveniles not identified to species; 3 very small unidentified juvenile vertiginids (Vertiginidae) excluded
3. Mostly *Z. nitidus*; small juveniles could not identified to species reliably

### 3.2.2 Relative abundance (ACO data)

Ten of 13 species of gastropods tested showed significant treatment effects in comparisons of relative abundance between pre- and post-logging periods (Table 6; see Appendix D for a summary of the data by plot). Eight of these species showed adverse effects consistent with logging (Figure 6). The 30% VR-dispersed treatment supported similar abundance as the control of two gastropods, *Pristiloma* snails and *H. vancouverense*, and of all small snails grouped together, while the numbers were greatly reduced in the clearcut and lower retention level treatments after logging (Tukey-Kramer HSD test, \( \alpha < 0.05 \)). The 30% retention VR-treatment tended to support more snails of three additional species (*Punctum randolphi*, *Nesovitrea binneyana*, *Planogryra clappi*), but pair-wise comparisons showed a statistical difference only between the control and all other treatments after logging (Tukey-Kramer HSD test, \( \alpha < 0.05 \)).

Two polygyrid snails, *Vespericola columbianus* and *Cryptomastix germana*, showed significant treatment effects, but the effects were inconsistent with the hypothesis of adverse impact of logging. *V. columbianus* had increased disproportionately in VR-groups within the 30% retention treatment and *C. germana* within the 10% retention treatment (Figure 6). It is possible that snails aggregated in the retention groups after the matrix was logged; alternatively, the effects may have been spurious due to factors other than logging.

There were no significant differences between pre- and post-logging periods in relative abundance of three species of gastropods: *Ariolimax columbianus*, *Euconulus fulvus*, and *Zonitoides* species (Table 6, Figure 6). These species were expected to be relatively tolerant. Herbivorous species such as *A. columbianus* (Pacific Banana Slug) may even benefit from the lush herbaceous growth in moist, recently logged areas, especially in moist sites. There was a significant plot effect for five species of gastropods (Table 6), indicating that their abundance showed a different pattern among plots during 2005 surveys when compared to 2001 surveys.
Table 6. Test statistics for comparison of relative abundance (number per artificial cover-object station) of individual species and groupings of gastropods between pre- and post-logging survey periods at the Horseshoe Lake Experimental Site (Manova). Data from artificial cover-objects. **Highlighted cells indicate significant effects**. Pre-logging period – 2001 (2 surveys for large species; 1 survey for small species), post-logging period – 2005 (3 surveys).

<table>
<thead>
<tr>
<th>Species or group</th>
<th>Treatment</th>
<th>Plot</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Wilks' lambda</td>
<td>F&lt;sub&gt;4,135&lt;/sub&gt;</td>
</tr>
<tr>
<td>Slugs:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ariolimax columbianus</td>
<td>0.9785</td>
<td>0.7406</td>
</tr>
<tr>
<td>Snails:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cryptomastix germana</td>
<td>0.8952</td>
<td>3.9530</td>
</tr>
<tr>
<td>Euconulus fulvus</td>
<td>0.9418</td>
<td>2.0842</td>
</tr>
<tr>
<td>Haplotrema vancouverense</td>
<td>0.8779</td>
<td>4.6940</td>
</tr>
<tr>
<td>Nesovitrea binneyana</td>
<td>0.7190</td>
<td>13.1907</td>
</tr>
<tr>
<td>Planogyra clappi</td>
<td>0.8396</td>
<td>6.4455</td>
</tr>
<tr>
<td>Pristiloma (stearnsii+lansingii)</td>
<td>0.8429</td>
<td>6.2912</td>
</tr>
<tr>
<td>Punctum randolphii</td>
<td>0.8636</td>
<td>5.3325</td>
</tr>
<tr>
<td>Striatura pugetensis</td>
<td>0.5889</td>
<td>23.5697</td>
</tr>
<tr>
<td>Vertigo species</td>
<td>0.8374</td>
<td>6.5528</td>
</tr>
<tr>
<td>Vespericola columbianus</td>
<td>0.6219</td>
<td>20.5206</td>
</tr>
<tr>
<td>Zonitoides (arboreus+nitidus)</td>
<td>0.9793</td>
<td>0.7149</td>
</tr>
<tr>
<td>Guilds:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Small snails (9 species combined)</td>
<td>0.5893</td>
<td>23.5225</td>
</tr>
</tbody>
</table>

1 Sequential Bonferroni correction was applied to achieve experiment-wide alpha of 0.1
Figure 6. Relative abundance of gastropod species in different treatment areas before and after logging at the Horseshoe Lake Experimental site, sampled with artificial cover-objects. Pre-logging surveys: Sept–Oct 2001; Post-logging surveys: Sept–Oct 2005, 3 – 4 years after logging; relative abundance: # of animals/sampling station averaged across surveys in both 2001 and 2005; n = 30 stations/treatment area.
Figure 6 (continued). Relative abundance of gastropod species in different treatment areas before and after logging at the Horseshoe Lake Experimental site, sampled with artificial cover-objects.

**Northwest Hesperian**
*(Vespericola columbianus)*

<table>
<thead>
<tr>
<th>Treatment Area</th>
<th>Mean #/ACO stn Pre-logging</th>
<th>Mean #/ACO stn Post-logging</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clearcut</td>
<td>0.5</td>
<td>1.0</td>
<td>&lt; 0.0001</td>
</tr>
<tr>
<td>VR-Dispersed-5%</td>
<td>1.0</td>
<td>0.5</td>
<td>&lt; 0.0001</td>
</tr>
<tr>
<td>VR-Dispersed-10%</td>
<td>0.5</td>
<td>1.0</td>
<td>&lt; 0.0001</td>
</tr>
<tr>
<td>VR-Dispersed-30%</td>
<td>1.5</td>
<td>1.0</td>
<td>&lt; 0.0001</td>
</tr>
<tr>
<td>Control</td>
<td>0.0</td>
<td>0.5</td>
<td>&lt; 0.0001</td>
</tr>
</tbody>
</table>

Not consistent with logging effects

**Western Flat-whorl**
*(Planogyra clappi)*

<table>
<thead>
<tr>
<th>Treatment Area</th>
<th>Mean #/ACO stn Pre-logging</th>
<th>Mean #/ACO stn Post-logging</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clearcut</td>
<td>0.0</td>
<td>0.5</td>
<td>&lt; 0.0001</td>
</tr>
<tr>
<td>VR-Dispersed-5%</td>
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<td>&lt; 0.0001</td>
</tr>
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<td>VR-Dispersed-10%</td>
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<td>4.0</td>
<td>&lt; 0.0001</td>
</tr>
<tr>
<td>VR-Dispersed-30%</td>
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<td>&lt; 0.0001</td>
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<tr>
<td>Control</td>
<td>6.0</td>
<td>2.0</td>
<td>&lt; 0.0001</td>
</tr>
</tbody>
</table>

**Blue Glass**
*(Nesovitrea binneyana)*

<table>
<thead>
<tr>
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<th>Mean #/ACO stn Pre-logging</th>
<th>Mean #/ACO stn Post-logging</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clearcut</td>
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<td>2.0</td>
<td>&lt; 0.0001</td>
</tr>
<tr>
<td>VR-Dispersed-5%</td>
<td>2.0</td>
<td>1.5</td>
<td>&lt; 0.0001</td>
</tr>
<tr>
<td>VR-Dispersed-10%</td>
<td>1.5</td>
<td>1.0</td>
<td>&lt; 0.0001</td>
</tr>
<tr>
<td>VR-Dispersed-30%</td>
<td>1.0</td>
<td>0.5</td>
<td>&lt; 0.0001</td>
</tr>
<tr>
<td>Control</td>
<td>0.0</td>
<td>0.5</td>
<td>&lt; 0.0001</td>
</tr>
</tbody>
</table>
Figure 6 (continued). Relative abundance of gastropod species in different treatment areas before and after logging at the Horseshoe Lake Experimental site, sampled with artificial cover-objects.

**Tightcoil snails** (*Pristiloma* spp)

**Conical Spot** (*Punctum randolphii*)

**Northwest Striate** (*Striatura pugetensis*)
Figure 6 (continued). Relative abundance of gastropod species in different treatment areas before and after logging at the Horseshoe Lake Experimental site, sampled with artificial cover-objects.

**Vertigo snails**  
*(Vertigo spp)*

![Graph showing the relative abundance of Vertigo snails before and after logging.]

**Brown Hive**  
*(Euconulus fulvus)*

![Graph showing the relative abundance of Brown Hive before and after logging.]

**Gloss snails**  
*(Zonitoides spp)*

![Graph showing the relative abundance of Gloss snails before and after logging.]

Legend:
- Pre-logging
- Post-logging

Statistical significance: *P < 0.0001*
Figure 6 (continued). Relative abundance of gastropod species in different treatment areas before and after logging at the Horseshoe Lake Experimental site, sampled with artificial cover-objects.

All small snails

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Pre-logging</th>
<th>Post-logging</th>
</tr>
</thead>
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<td>15.0</td>
</tr>
<tr>
<td>VR-Dispersed-5%</td>
<td>5.0</td>
<td>10.0</td>
</tr>
<tr>
<td>VR-Dispersed-10%</td>
<td>15.0</td>
<td>20.0</td>
</tr>
<tr>
<td>VR-Dispersed-30%</td>
<td>20.0</td>
<td>25.0</td>
</tr>
<tr>
<td>Control</td>
<td>10.0</td>
<td>15.0</td>
</tr>
</tbody>
</table>

P < 0.0001
3.2.3 Relative abundance (litter data)

The overall abundance of small snails had decreased precipitously, by 69%, during the four-year period from 2001 to 2005; Figure 7; Appendix E). There was a statistically significant "time" effect for five of the species tested (Table 7). While in most cases abundance had remained similar in the control area as in 2001, it had decreased variously in the logged treatments in 2005 (Figure 7). However, the treatment effect was not statistically significant for any of the species tested, probably due to small sample sizes and high variability within treatments; there was only 1 sample per plot, resulting in a total of 3 samples per treatment (Table 7). The following trends were observed (Figure 7): Densities of Pristiloma snails, Planogyra clappi, Striatura pugetensis, and all small snails combined tended to be depressed in the 10% retention, 5% retention and clearcut treatments when compared to the control and 30% retention treatment; densities of Nesovitrea binneyana and Zonitoides species tended to be depressed in the 5% retention and clearcut treatments when compared to the 10% retention, 30% retention, and control treatments; densities of Vertigo species and Punctum randolphii tended to be depressed in all logged treatments when compared to the control.

Table 7. Test statistics for comparison of average density (#/liter/plot) of individual species and groupings of small snails between pre- and post-logging survey periods at the Horseshoe Lake Experimental Site (Manova for repeated measures). Data from litter samples. Highlighted cells indicate significant effects¹. Pre-logging period - 2001, post-logging period - 2005. Insufficient observations for comparisons existed for 1 additional species (Columella edentula).

<table>
<thead>
<tr>
<th>Species or group</th>
<th>Treatment</th>
<th></th>
<th>Time</th>
<th></th>
<th>Time x Treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Wilks' lambda</td>
<td>F4,10</td>
<td>P</td>
<td>Wilks' lambda</td>
<td>F1,10</td>
</tr>
<tr>
<td>Euconulus fulvus</td>
<td>0.5775</td>
<td>1.8509</td>
<td>0.1959</td>
<td>0.8004</td>
<td>2.4545</td>
</tr>
<tr>
<td>Nesovitrea binneyana</td>
<td>0.5873</td>
<td>1.7568</td>
<td>0.2140</td>
<td>0.7158</td>
<td>3.9700</td>
</tr>
<tr>
<td>Planogyra clappi</td>
<td>0.6739</td>
<td>1.2100</td>
<td>0.3655</td>
<td>0.4307</td>
<td>13.2191</td>
</tr>
<tr>
<td>Pristiloma spp (P. stearnsii &amp; P. lansingii)</td>
<td>0.4972</td>
<td>2.5279</td>
<td>0.1068</td>
<td>0.5094</td>
<td>9.6294</td>
</tr>
<tr>
<td>Punctum randolphii</td>
<td>0.6469</td>
<td>1.3647</td>
<td>0.3133</td>
<td>0.2299</td>
<td>33.5058</td>
</tr>
<tr>
<td>Striatura pugetensis</td>
<td>0.5841</td>
<td>1.7799</td>
<td>0.2094</td>
<td>0.2566</td>
<td>28.9762</td>
</tr>
<tr>
<td>Vertigo spp</td>
<td>0.6437</td>
<td>1.3836</td>
<td>0.3075</td>
<td>0.2135</td>
<td>36.8403</td>
</tr>
<tr>
<td>Zonitoides spp (Z. arboreus and Z. nitidus)</td>
<td>0.7194</td>
<td>0.9751</td>
<td>0.4630</td>
<td>0.5562</td>
<td>7.9779</td>
</tr>
<tr>
<td>All small snails (combined)</td>
<td>0.6230</td>
<td>1.5130</td>
<td>0.2707</td>
<td>0.2129</td>
<td>36.9747</td>
</tr>
</tbody>
</table>

¹Sequential Bonferroni correction was applied to achieve experiment-wide alpha of 0.1
Figure 7. Density of small snails (# of snails/1 liter of litter) based on litter samples collected during pre-logging and post-logging periods at the Horseshoe Lake Experimental Site. Dead shells excluded. 2001 (pre-logging): 1 sample of 2.5 liters collected per plot; 2005 (post-logging): 2 samples of 2.5 liters collected per plot.

**Tightcoil snails**
(*Pristiloma* spp)

**Blue Glass**
(*Nesovitrea binneyana*)

**Brown Hive**
(*Euconulis fulvus*)
Figure 7 (continued). Density of small snails (# of snails/1 liter of litter) based on litter samples collected during pre-logging and post-logging periods at the Horseshoe Lake Experimental Site.

**Western Flat-whorl**  
*Planogyra clappi*  

**Conical Spot**  
*Punctum randolphii*  

**Northwest Striate**  
*Striatura pugetensis*
Figure 7 (continued). Density of small snails (# of snails/1 liter of litter) based on litter samples collected during pre-logging and post-logging periods at the Horseshoe Lake Experimental Site.

**Vertigo snails**
(Vertigo spp)

**Gloss snails**
(Zonitoides spp)

**All small snails (9 spp.)**
3.2.4 Species diversity and richness

Species diversity, as measured by the Shannon-Wiener index, showed a significant treatment effect in pre- and post-logging comparisons (Table 8; see Appendix F for values per plot). The effect was largely due to reduced diversity in all plots within the 5% treatment after logging (Figure 8); in pair-wise comparisons, species diversity in this treatment was significantly lower than in the control and 30% retention treatment (Tukey-Kramer HSD test, $\alpha < 0.05$). However, the pattern was inconsistent with adverse effects of logging, as species diversity in the clearcut treatment was not depressed. We suspect that the effect was site-specific to the 5% treatment area and spurious with respect to logging effects. No treatment effects were evident in the number of species detected per plot, although there was a significant “time” effect, indicating that the pattern was different in 2005 from that in 2001 (Table 8). This difference most likely represented overall reduction in numbers of gastropods in all logged treatments and consequent reduction in the probability of detecting species in each plot.

Table 8. Horseshoe Lake: Test statistics for comparison of species diversity (Shannon's $H'$) and species richness between pre- and post-logging periods. Values calculated for each plot based on total number caught per season using artificial cover-objects.

<table>
<thead>
<tr>
<th>Effect</th>
<th>A. Shannon's $H'$</th>
<th>B. # of species</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Wilks' lambda</td>
<td>F</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Treatment</td>
<td>0.3214</td>
<td>5.278</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.6731</td>
</tr>
<tr>
<td>Time</td>
<td>0.9013</td>
<td>1.095</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.5605</td>
</tr>
<tr>
<td>Treatment x Time</td>
<td>0.4338</td>
<td>3.263</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.4770</td>
</tr>
</tbody>
</table>
Figure 8. Comparison of species diversity (Shannon-Wiener index) and species richness (# of species detected per plot) of terrestrial gastropods among different logging treatments during pre- and post-logging periods at the Horseshoe Lake Experimental Site.

A. Horseshoe Lake: Species Diversity

![Species Diversity Graph]

B. Horseshoe Lake: Species Richness

![Species Richness Graph]
4.0 CONCLUSIONS

At the Tsitika Experimental Site, 2 of 7 gastropods tested showed effects consistent with logging (significantly lower abundance in logged areas than the control) in comparisons of pre- and post-logging data of relative abundance within VR-groups, based on sampling with artificial cover-objects. These gastropods were *Pristiloma* species (*P. stearnsii* and unidentified juveniles) and *Striatura pugetensis*; both are small snails that are associated with moist forest floor conditions. There were no significant differences among the VR-treatments, but the clearcut treatment tended to have the lowest abundance of both species. Effects of the different retention levels on abundance of gastropods within the retention patches could become more pronounced over time, as dispersal from group to group might be facilitated within the higher retention level treatments.

At the Horseshoe Lake Experimental Site, 10 of 13 species tested showed significant treatment effects in pre- and post-logging comparisons; effects for 8 of 10 species were consistent with adverse effects of logging, while 2 were inconclusive. Gastropods with effects consistent with logging included 7 species of small litter-dwelling snails and a large carnivorous snail (*Haplotrema vancouverense*). The VR-dispersed treatment with 30% VR-retention level was statistically indistinguishable from the control for two sensitive gastropods (*Pristiloma* spp and *H. vancouverense*) and for all small snails combined; 3 additional species showed a trend towards greater relative abundance in the 30% dispersed treatment when compared to the other logging treatments (10% and 5% retention level and clearcut).

Extraction of small snails (shell diameter < 5 mm) from litter samples showed that abundance had increased across all treatments from 2001 to 2005 at the Tsitika site, probably as a result of natural multi-year fluctuations or weather conditions. In contrast, densities had decreased precipitously during the same period at the Horseshoe Lake site, especially within the logged areas. Overall, the trends were similar to effects found with artificial cover-object sampling. However, no statistically significant logging effects were found in the litter sample data for either site, likely due to small sample sizes and high variability among plots.

In conclusion, we detected relatively few effects attributable to logging at the Tsitika Experimental Site, whereas decreased abundance of many species at the Horseshoe Lake Experimental Site was consistent with adverse effects of logging. The two sites were very different in terms of habitat and characteristics of gastropod faunas, and responses of gastropods to logging most likely reflected these differences. Extensive blow-down in the VR-groups at Tsitika also complicated the results. Due to high densities and diversity of species, the Horseshoe Lake site provided an excellent opportunity to examine effects of logging on small litter-dwelling snails. Post-logging surveys at the four remaining experimental sites to be conducted in 2006 and 2007 will help clarify the effects of variable retention logging practices and provide replication.
5.0 LITERATURE CITED


Appendix A. Tsitika Experimental Site: Number of gastropods found during artificial cover-object (ACO) inspections per sampling plot in May - June 2001 and 2005. PRE: pre-logging period (3 surveys in 2001); POST: post-logging period (3 surveys in 2005).

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Plot ID</th>
<th>ANC spp</th>
<th>ARICO</th>
<th>COLED</th>
<th>HAPVA</th>
<th>PLACL</th>
<th>PRI spp</th>
<th>PROFO</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clearcut</td>
<td>CC1</td>
<td>0</td>
<td>0</td>
<td>7</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>Clearcut</td>
<td>CC2</td>
<td>0</td>
<td>0</td>
<td>6</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Clearcut</td>
<td>CC3</td>
<td>0</td>
<td>0</td>
<td>7</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Clearcut</td>
<td>CC4</td>
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<td>0</td>
<td>11</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>VR-group-10%</td>
<td>GR1-10%</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>2</td>
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<tr>
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<table>
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<th>STRPU</th>
<th>VER spp</th>
<th>VESCO</th>
<th>All slugs</th>
<th>All small snails</th>
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</thead>
<tbody>
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<td>1</td>
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<tr>
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<td>CC2</td>
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<td>0</td>
<td>4</td>
<td>0</td>
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<td>3</td>
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<td>1</td>
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</tr>
<tr>
<td>VR-group-20%</td>
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<td>VESCO</td>
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<td>All small snails</td>
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Appendix B. Tsitika Experimental Site: Density (#/liter of litter) of small snails extracted from 5 liters of litter collected at each plot during pre- and post-logging periods in 2001 and 2005, respectively.

A. Snails live at the time of collection:

<table>
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<th>PUNRA</th>
<th>STRPU</th>
<th>VER spp</th>
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<td>PRE</td>
<td>POST</td>
<td>POST only</td>
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<td>CC1</td>
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<td>1.6</td>
<td>1.8</td>
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<td>1.6</td>
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<td>0.2</td>
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<td>0.4</td>
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<td>0.2</td>
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<td>0.0</td>
<td>0.4</td>
<td>0.6</td>
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<td>GR4-30%</td>
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<td>0.0</td>
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<td>1.6</td>
<td>0.0</td>
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<td>0.6</td>
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<tr>
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<td>0.4</td>
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\(^1\) Plot CC3 showed unusually large numbers of small snails and was near edge of old growth after logging (within 30 m).
### Appendix C. Tsitika Experimental Site: Species diversity (Shannon-Wiener index) and richness of gastropods per plot during pre- and post-logging periods.

Data for 3 surveys during each period were combined.

<table>
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<th># species:</th>
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### Appendix D. Horseshoe Lake Experimental Site: Number of gastropods found during artificial cover-object (ACO) inspections per sampling plot in September - October 2001 and 2005.

See Table 5 for codes. PRE-pre-logging period (2 surveys in 2001; 1 only for small snails); POST-post-logging period (3 surveys in 2005).

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<td>D2-10%</td>
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<td>2</td>
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<td>D3-10%</td>
<td>14</td>
<td>28</td>
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<td>1</td>
<td>9</td>
<td>3</td>
<td>10</td>
<td>14</td>
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</table>
### Appendix E. Horseshoe Lake Experimental Site: Density (#/1 liter of litter) of small snails extracted from litter collected at each plot during the pre- and post-logging periods.

2001 (pre-logging): 1 sample of 2.5 liters collected per plot; 2005 (post-logging): 2 samples of 2.5 liters collected per plot

#### A. Snails live at the time of collection:

<table>
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<tr>
<th>Treatment</th>
<th>Plot ID</th>
<th>COLED pre</th>
<th>EUCFU pre</th>
<th>NESBI post</th>
<th>PLACL pre</th>
<th>PRI spp post</th>
<th>PUNRA pre</th>
<th>STRPU post</th>
<th>VER spp post</th>
<th>VESCO pre</th>
<th>ZON spp post</th>
<th>All small snails post</th>
</tr>
</thead>
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<td>CC1</td>
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<td>0.8</td>
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<td>11.2</td>
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<td>4.4</td>
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<td>2.6</td>
<td>7.6</td>
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<td>3.6</td>
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<td>0.2</td>
<td>0.8</td>
<td>1.2</td>
<td>0.8</td>
<td>3.2</td>
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</tr>
<tr>
<td>Control</td>
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<td>1.8</td>
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</tr>
<tr>
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<td>0.0</td>
<td>0.8</td>
<td>0.4</td>
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<td>54.48</td>
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<td>1450.910</td>
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</table>

#### B. Snails dead at the time of collection (empty shells):

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<th>EUCFU pre</th>
<th>NESBI post</th>
<th>PLACL pre</th>
<th>PRI spp post</th>
<th>PUNRA pre</th>
<th>STRPU post</th>
<th>VER spp post</th>
<th>VESCO pre</th>
<th>ZON spp post</th>
<th>All small snails post</th>
</tr>
</thead>
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<tr>
<td>Clearcut</td>
<td>CC1</td>
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<td>0.0</td>
<td>0.0</td>
<td>0.8</td>
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<td>2.4</td>
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<td>0.6</td>
<td>4.0</td>
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<td>Clearcut</td>
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<td>7.6</td>
<td>17.2</td>
</tr>
</tbody>
</table>

| All small snails     | 17.2    | 8.2       | 16.4      | 11.0       | 37.2      | 3.4       |
Appendix F. Horseshoe Lake Experimental Site: Species diversity (Shannon-Wiener index) and richness of gastropods per plot during pre- and post-logging periods. Data for all surveys during each period were combined.

<table>
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<th>COLED post</th>
<th>EUCFU pre</th>
<th>EUCFU post</th>
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<th>NESBI post</th>
<th>PLACL pre</th>
<th>PLACL post</th>
<th>PRI spp pre</th>
<th>PRI spp post</th>
<th>PUNRA pre</th>
<th>PUNRA post</th>
<th>STRPU pre</th>
<th>STRPU post</th>
<th>VER spp pre</th>
<th>VER spp post</th>
<th>ZON spp pre</th>
<th>ZON spp post</th>
<th>All small snails pre</th>
<th>All small snails post</th>
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Note: Ancotrema, Pristiloma, Vertigo, & Zonitoides spp were counted as 1 species each in this analysis.