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Grylloblattids in Managed Forests of South-central British Columbia

Abstract

We collected 147 specimens of grylloblattids (*Grylloblatta campodeiformis*) in pitfall traps in subalpine spruce-fir forest and lower elevation cedar-hemlock forest at two study sites in south-central British Columbia. Grylloblattids are of conservation interest because of the high degree of endemism in western North America and because little is known of the ecology of these insects. Mature grylloblattid individuals were caught primarily in early spring or late fall, while immature individuals were caught in traps set under the snow in winter. Grylloblattids occurred in clearcuts, partial cuts and uncut forest at both sites. Year-round collections of grylloblattids from a variety of forest habitats have not previously been reported. However, the insects were rare at one study site in old clearcuts and had different seasonal patterns of captures in recent clearcuts with intensive site preparation compared to partially-cut or uncut areas. At a second study site, they showed an affinity for cutblock edges and small patch cut harvest treatments that produce abundant edge. No grylloblattids were collected during similar sampling at a third site in dry Douglas-fir forest. The unexpected abundance of grylloblattids at two sites suggests that they may be widespread in wetter forest sites, but dry forests with low snowfall may act as a geographic barrier. Grylloblattids appear to tolerate or benefit from forest harvesting, other than in large clearcuts with intensive site preparation.

Introduction

Notoptera is one of the rarest and least-known insect orders, comprising two genera in Asia and one genus, *Grylloblatta*, found only in western North America (Rentz 1982). One species of grylloblattid, *Grylloblatta campodeiformis*, has been found in the Rocky Mountains in Canada and the northern United States, in isolated locations in northern British Columbia and along the Thompson River drainage in south-central British Columbia (Kamp 1979). At least nine other species in the genus *Grylloblatta* occur in apparently relict populations in the Coast and Cascade Mountains from southwestern British Columbia to northern California (Rentz 1982). Kamp (1979) attributed the geographic distribution of species in this genus to isolation of the coastal species in glacial refugia during the Pleistocene.

Grylloblattids are cold-adapted (Ford 1926, Mills and Pepper 1937, Kamp 1973), with a preferred temperature at high relative humidity of -3.5°C to $+5^{\circ}\text{C}$, and optimal temperature of $+1.7^{\circ}\text{C}$ (Henson 1957a, Kamp 1973). Due to these nar-

row microclimatic preferences, this species is often thought to occur primarily in high-elevation areas near snow-fields or glaciers that provide cold, moist conditions throughout the year (Ford 1926, Kamp 1973, Edwards 1982). Grylloblattids are closely associated with the alpine or subalpine hypolithion, the layer in or under rock fields, where crevices provide suitable micro-climates in extreme summer and winter conditions (Kamp 1973, 1979). Presence at moderate elevations is associated with extensive rockpiles and cooling by subsurface flows of melt water (Kamp 1973, Pritchard and Scholefield 1978, Edwards 1982). Further corroborating the idea that grylloblattids require special habitat features to meet their narrow micro-climate preferences, one exceptional population at low elevation in a semi-desert environment near Kamloops, British Columbia, was restricted to a deep talus slope. This habitat feature allowed access to ground temperatures near freezing year-round, despite mid-summer air temperatures $>40^{\circ}\text{C}$ (Campbell 1949). The rarity and patchy nature of apparently suitable habitat types led Kamp (1979) to postulate that North American grylloblattids occurred in highly disjunct distributions, with local populations largely isolated by unsuitable habitat.

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In northern coniferous forests, however, numerous features other than permanent ice and snow fields or talus slopes can provide moist microhabitats with low temperatures in summer, including deep moss layers, large logs, and dense vegetation cover. In winter, deep snowpacks can insulate the ground surface and maintain moist, near-freezing conditions throughout the area. We report the collection of numerous grylloblattids at two forest sites in south-central British Columbia, which demonstrate that the habitat requirements and distribution of this species of grylloblattid may not be as restrictive as previously believed. Because forest management affects ground microclimate and snow accumulation (Golding 1982, Chen et al. 1995) and alters some of the forest characteristics that could provide suitable microhabitats for grylloblattids, such as the moss layer (Stokland 1991) and coarse woody debris (Harmon et al. 1986), conservation of this rare order could be a concern in managed forests. Our primary objective was to document the distribution of grylloblattids in forest habitats and to provide an assessment of the possible effects of forest management on this species. We used a retrospective treatment design at one study site and large-scale experimental manipulations at a second site for this purpose. We also report results from a third study area in dry Douglas-fir forest, for our secondary objective of improving understanding of the biogeography of the genus.

Methods

Study sites

The East Barriere Lake (EBL) study site is located south of East Barriere Lake, 75 km north-east of Kamloops, British Columbia. Elevations in the 6 km x 8 km study area range from 1000 m in the valley bottoms to 1750 m on the tops of ridges. Forests below 1350 m are in the Interior Cedar-Hemlock (ICH) biogeoclimatic zone, and above 1350 m in the Engelmann spruce-subalpine fir (ESSF) zone (Lloyd et al. 1990). The ICH is considered interior temperate rain forest, with a closed canopy forest of western redcedar (*Thuja plicata*), western hemlock (*Tsuga heterophylla*), Douglas-fir (*Pseudotsuga menziesii*) and other conifers, and a variety of early seral deciduous species (Lloyd et al. 1990). The ESSF zone is subalpine forest with a more open canopy of Engelmann spruce (*Picea engelmannii*) and subal-

pine fir (*Abies lasiocarpa*), and white-flowered rhododendron (*Rhododendron albiflorum*) as the dominant shrub species (Lloyd et al. 1990). The alpine areas nearest to the site are 25 km to the north and 32 km to the east. A deep snowpack is present from mid-October until June in the ESSF zone, and from late-October until May in the ICH. Summers are generally cool and wet. Forests have been harvested in the area for 40 yr.

The EBL study used three replicate cutblocks or stands of the following seven treatments:

1. ESSF uncut forest. These stands are all > 140 yr old.

2. ESSF partial cut. Approximately 50% of the timber volume was removed from these stands 15–25 yr before the study, with an emphasis on harvesting Engelmann spruce and larger subalpine fir. Coarse woody debris and shrub cover are abundant on these sites.

3. ESSF clearcut. All trees on these blocks were removed 15–20 yr before the study. The sites were burned, mechanically scarified, and planted with Engelmann spruce. The planted trees are < 1.5 m tall, the sites are dominated by annual herbs, and coarse woody debris is scarce.

4. ICH uncut. Two of the three study stands are old-growth redcedar and hemlock (> 250 yr old); the other is natural second-growth Douglas-fir and redcedar (130 yr old).

5. ICH partial cut. 20–50% of the timber volume was removed from these sites 20–35 yr before the study, with an emphasis on harvesting western white pine (*Pinus monticola*) and Engelmann spruce. These sites are at the upper elevation limit of ICH, where preferred tree species occurred. The sites have wide, herb- and shrub-dominated logging trails interspersed with thick deciduous and conifer regeneration under the canopy conifers.

6. ICH old clearcut. All trees on these sites were removed 15–25 yr ago, and the sites were burned and planted. Regeneration is dominated by deciduous species and shrub cover is tall and dense.

7. ICH recent clearcut. These sites were harvested 2–5 yr prior to the start of the study, then burned and planted. Regenerating conifers are < 1.5 m tall and the sites are dominated by annual herbs.

The Sicamous Creek (SC) site is an experimental silvicultural systems site in ESSF forest, located 8 km southeast of Sicamous, British Columbia (Vyse 1999). The site is north-facing, at elevations between 1550 m and 1800 m. A deep snowpack is present from late September until late June; summers are cool and wet. The site was unlogged old forest until winter 1994-95, when five experimental harvest treatments were applied: 1. Single 10-ha clearcut, 2. Array of nine 1-ha patch cuts, 3. Array of fifty-five 0.1-ha patch cuts, 4. Individual tree selection cut, 5. Uncut control. Three replicates of each treatment were applied in a randomized block design to fifteen 30-ha experimental units. With associated roads and landings, each of the four harvest treatments removed 33% of the trees in a unit. In addition to the five overall treatments, the experiment created four harvest types: 1. Clearcut—within the 10-ha, 1-ha or 0.1-ha openings > 10 m from the forest edge, 2. Edge—within 5 m of the edge of the clearcut opening and the forest, 3. Partial cut—within the individual-tree selection harvests, 4. Uncut—in either the uncut control blocks or >10 m from an opening in the forested leave strips of the patch-cut or clearcut treatment blocks.

The Opax Mountain (OM) study area is also an experimental silvicultural systems site, in the Interior Douglas-fir zone (IDF) (Lloyd et al. 1990), 15 km northwest of Kamloops, British Columbia. The site is dominated by Douglas-fir, with a pinegrass (*Calamagrostis rubescens*) understory, on varied topography of volcanic origin. Summers are hot and dry; winters are cold with relatively little snow accumulation and frequent freezing of the ground down to the mineral soil. Experimental harvest treatments in twelve 20-ha units at the site created a range of forest conditions, including 1.6-ha and smaller patch cuts, 50% and 20% removal partial cuts, uncut stands, and leave strips.

Sampling Design

We sampled ground-dwelling invertebrates using pitfall traps consisting of 400-ml smooth plastic beverage cups with 9.5 cm diameter top set flush with the ground surface. A 30 x 30 cm board held on stakes 15 cm above each trap kept out rain and debris. For summer trapping, 5 pitfall traps were arranged in a trap circle of 7 m diameter. Three trap circles, 50-75 m apart, were used to subsample each replicate block at EBL and SC,

for a total of 15 pitfall traps per replicate block. In 1996, an additional set of three circles was added to each block at SC, for a total of 30 pitfall traps per block. Two sets of five circles were used in each replicate block at OM. For winter trapping, each circle had one pitfall trap under a 1.2 m tall plywood chimney supported 10 cm above the cup on a 60 x 60 cm base board. Chimneys were 30 x 30 cm, with a plywood lid, and 5-cm thick foam insulation at three levels. In 1993/94, we increased winter trapping effort to three chimneys per trap circle at EBL and SC. Some of the additional winter traps at SC used 10 cm diameter plastic pipes to form chimneys, also insulated with foam. Temperature probes with automatic readings throughout the day and night showed that the ground temperature under both types of chimneys and under undisturbed snowpack remained near 0°C from December to May.

Pitfall traps were set by adding 100 ml of a mixture of 35% water and 65% propylene glycol, a non-volatile antifreeze, to the pitfall cup. In snow-free seasons, samples were collected after 2 wk, the glycol was replenished and a second sample was collected 2 wk later. In winter, the traps were set in early January through the chimney without disturbing the snow cover and collected 2 mo later. All grylloblattids in the samples were removed from the samples. Body length was measured from the front of the head to the base of the cerci using an ocular micrometer. Individuals ≥ 10 mm in length were considered mature or submature; individuals <10 mm in length were considered immature. Fully mature individuals with external genitalia and darkened exoskeletons were between 13 mm and 16 mm long.

Samples were collected at EBL in June (1994-1996), July (1994), August-September (1991-1995), October (1994-1995), and winter (1992/93-1995/96). Samples were collected at SC in July (1996-1997), August (1992-1997), and winter (1993/94 and 1995/96-1996/97). Harvesting at SC occurred in winter 1994/95. Samples at OM were collected in: May-June (1995-1997), July-August (1994-1996), September-October (1993, 1995-1996), and winter (1994/95-1996/97). For seasonal summaries, 2-wk sessions in May or June were considered spring, sessions in July or August were considered summer, and sessions in September or October were considered autumn.

TABLE 1. Trapping effort, number of grylloblattids collected, and body lengths at the East Barriere Lake (EBL) and Sicamous Creek (SC) study sites. Immatures are defined as individuals with body length <10 mm.

Site	Season	Trap-days	Grylloblatid specimens		Length (mm)		% Immature
			Number	per 10,000 trap-days	Mean	SD	
EBL	Spring	15,484	14	9.0	13.6	2.2	0.0
	Summer	36,526	4	1.1	14.9	1.2	0.0
	Autumn	21,420	19	8.9	12.9	3.0	0.0
	Winter	36,152	41	11.3	6.3	2.2	95.1
SC	Summer	64,358	20	3.1	15.0	0.9	5.0
	Winter	33,166	49	14.8	6.7	3.6	84.4

Statistical tests of treatment effects at EBL used a single-factor ANOVA. Tests of overall treatment effects and effects of finer-scale harvest types at SC used a randomized block ANOVA. A significance level of 0.05 was used.

Results

We collected 78 grylloblattids in 109,582 pitfall trap-days at EBL. Four adult males from EBL have been identified as *Grylloblatta campodeiformis campodeiformis* (Vernon R. Vickery, Lyman Museum, McGill University, Montreal, Quebec, personal communication). Grylloblattids at EBL were collected primarily in winter, in spring just after snowmelt, or in fall just prior to snowfall (Table 1). Few were collected in summer, despite high levels of trapping effort in that season.

Grylloblattids were found in 18 of the 21 replicate blocks across the EBL site, including open rocky clearcuts, thick brushy sites, and mossy old-growth forest at low and high elevations. The three blocks where grylloblattids were not found had no obvious common features and included one open ESSF partial cut, one rocky ESSF clearcut, and one old ICH clear cut with dense vegetation. Grylloblattids were present in all treatment types, but the temporal pattern of captures differed between the ICH and ESSF sites, with many ESSF captures in snow-free seasons and most ICH captures in the winter under the snowpack (Figure 1). Grylloblattid abundance in snow-free seasons generally increased with elevation, being high in ESSF sites, moderate in the ICH partial cuts at middle elevations and lowest in the other ICH sites at lower elevations, even though treatment differences were not statistically significant in these seasons. Abundance in winter did differ signifi-

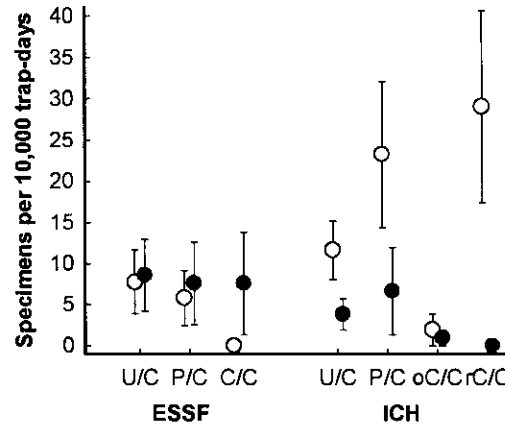


Figure 1. Grylloblattids captured per 10,000 pitfall trap-days in summer (closed circles) and winter (open circles) in seven treatments at EBL. ESSF = Engelmann spruce-subalpine fir forest, ICH = Interior cedar-hemlock forest, U/C = uncut, P/C = partial cut, C/C = clearcut, oC/C = old clearcut, rC/C = recent clearcut. Error bars are 1 S.E.

cantly between treatments (Figure 1), without any apparent relationship to elevation or snow depth and duration.

Individuals collected in winter at EBL were generally small and immature, while individuals collected from spring through fall were larger submature or mature (Table 1). The low standard deviation of body lengths (Table 1) demonstrates the limited range of body sizes collected in each season. The difference in size is a seasonal effect. It is not due to ICH individuals dominating winter samples and ESSF individuals dominating snow-free samples, because all seven winter specimens from ESSF were also immature, and 9 of 13 ICH specimens from snow-free seasons were mature or submature.

Grylloblattid captures per 10,000 trap-days at SC in summer and winter were similar to the values for those seasons at EBL (Table 1). Immature individuals similarly dominated winter samples and all but one summer specimen was mature or submature. Grylloblattids were present in all study blocks across the relatively homogeneous SC site, and were found in all treatment types and harvest types after logging. Catch of grylloblattids per unit effort in winter was the same in pre-harvest forest and post-harvest clearcuts and uncut forest, while partial cuts had somewhat fewer grylloblattids (Figure 2). Grylloblattid abundance was significantly higher on the edges of clearcuts,

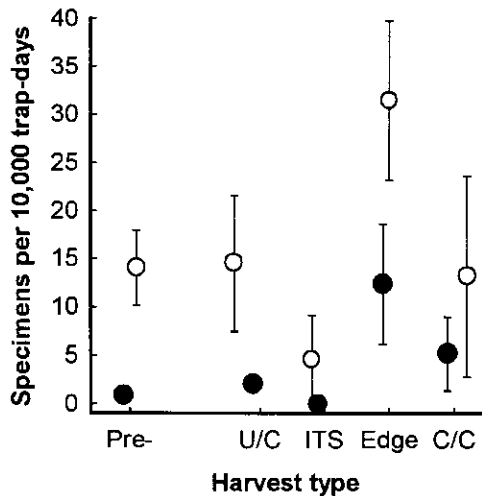


Figure 2. Grylloblattids captured per 10,000 pitfall trap-days in summer (closed circles) and winter (open circles) at SC by harvest type. Pre- = uncut forest prior to harvesting, U/C = uncut controls and leave strips, ITS = individual-tree selection partial cut, Edge = within 5 m of clearcut-forest edge, C/C = clearcut sites in 0.1-ha, 1-ha or 10-ha openings. Error bars are 1 S.E.

in both summer and winter (Figure 2). Correspondingly, catch per unit effort tended to be higher in the 0.1-ha patch cut array treatment, which has large amounts of edge, although overall treatment effects were highly variable and not statistically significant (Figure 3).

No grylloblattids were collected at OM in 13,594 trap-days in spring, 22,008 trap-days in summer, 26,572 trap-days in autumn or 34,328 trap-days in winter.

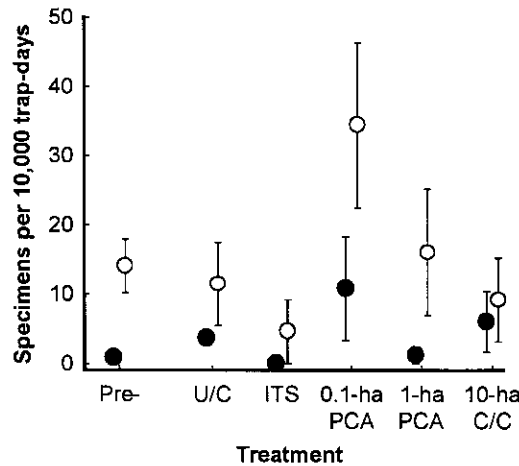


Figure 3. Grylloblattids captured per 10,000 pitfall trap-days in summer (closed circles) and winter (open circles) at SC by overall treatment. Pre- = uncut forest prior to harvesting, U/C = uncut controls and leave strips, ITS = individual-tree selection partial cuts. The patch-cut arrays (PCA) and 10-ha clearcut (C/C) treatments include the openings and uncut leave strips. Error bars are 1 S.E.

Discussion

This study is the first to report year-round occurrence of grylloblattids in a wide variety of forested habitats. The ubiquity of grylloblattids at the East Barriere Lake and the Sicamous Creek sites, and even their presence there, was not expected from previous reports of their restrictive habitat preferences and patchy distribution. However, the results from these two study areas are likely not ecological anomalies. Instead, we believe that the unexpectedly large collections of grylloblattids are due to the use of pitfall traps throughout the year. Pitfall traps have rarely been used to sample arthropods in higher-elevation forests in western North America, particularly in winter. Previous collections of grylloblattids have relied on active searching, during which collectors tend to concentrate on habitats and locations thought to be favorable for the species (Ford 1926, Kamp 1973), perhaps falsely indicating a restricted habitat tolerance and distribution. Active searching would be unlikely to find grylloblattids inhabiting forest floor materials, and would not detect activity under the snow. Future studies of this group should use pitfall traps, particularly in winter, early spring, and late fall.

The dominance of small individuals in winter samples and large, mature individuals in snow-free samples indicates different seasonal activity patterns for the two groups, rather than indicating the phenology of the species, because grylloblattids are known to remain in juvenile stages and to live as adults for several years (Henson 1957b). The stable microclimatic conditions under snow and reduced activity of predaceous arthropods may be more favorable to small grylloblattids than conditions at snowfree times, while the larger adults may be less sensitive to variable microclimates and increased predators in snowfree periods. However, this explanation does not account for the rarity of adults in winter samples.

Several conditions could make the dry Douglas-fir forest, represented by the OM site, unsuitable for grylloblattids. Summers are hot and dry, with shallow soils and solid bedrock providing few opportunities for cool refugia. Large well-decayed coarse woody debris is rare, due to frequent fires. Low winter temperatures without a deep insulating snowpack allow the ground to freeze, eliminating the moist, near-freezing subnivean spaces found in ICH and ESSF forests, IDF forests, and even drier habitat types, extend south from central British Columbia through the British Columbia Interior, expanding into the Great Basin of the western United States. This band of habitat that is currently unsuitable for grylloblattids may provide an alternative or complementary mechanism to Kamp's (1979) Pleistocene glacial explanation of the isolation of west-coast grylloblattid species from *G. campodeiformis* in the Rocky and Selkirk mountain areas. If these dry, low-snowfall ecosystems are important dispersal barriers for grylloblattids, undiscovered populations could be expected in isolated areas with wetter forests and deeper snowpacks within the Great Basin and its extension into British Columbia.

Grylloblattids were originally discovered in western Canada, and half of the approximately 20 species currently recognized in the order are endemic to western North America (Rentz 1982). With a high degree of endemism, the order should be an important conservation concern where it occurs in western North America. Previous portrayal of the group's typical habitat as isolated

alpine areas, rock, snow fields, and ice caves suggested that forest management was not a conservation issue for grylloblattids. However, we have shown that grylloblattids are forest-dwelling species in at least two common forest types in British Columbia.

In this study, grylloblattids tolerated a wide range of managed forest conditions, but there was some indication that they are affected by harvesting that uses large clearcuts and intensive site preparation. In ESSF forest at EBL, grylloblattids in snow-free seasons (mature and submature individuals) were found in similar abundance in uncut, partially cut, and clearcut forests, but no winter specimens (immature individuals) were collected in ESSF clearcuts. In contrast, the recent ICH clearcuts had many immature individuals but lacked mature adults, while uncut and partial cut ICH forest had both mature and immature individuals. Old ICH clearcuts had few of either age class. The absence of grylloblattids in clearcuts in one season or the other suggests that clearcuts with intensive site disturbance cannot maintain all life stages of the species, warranting concern about the effects of harvesting on these insects.

In the ESSF forest at the experimental SC site, there was no difference in abundances of grylloblattids, including mature and immature animals, between clearcut areas, uncut controls, or pre-harvest uncut forest. In contrast to EBL, clearcuts at SC have not been burned or subject to intensive site preparation. Additionally, the relatively high abundance of grylloblattids along cutblock edges suggests that they may benefit from the abundant edge created by small openings. The increasing operational use of alternatives to large clearcuts and less severe site preparation should help to ensure the conservation of this unique insect species in managed forests.

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