ical endeavors where a measurement of free water is required. Completely assembled, the system, including a weather shelter for the recorder, cost less than $300.

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Mountain Pine Beetle[1] Brood Production in Relation to Thickness of Lodgepole Pine Phloem[2]

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ABSTRACT

The effects of phloem thickness of lodgepole pine, *Pinus contorta* Douglas, and number of inches of egg gallery of *Dendroctonus ponderosae* Hopkins on brood production of the beetle were investigated in laboratory studies. Brood production ranged from an average of 16 beetles for phloem 0.09 inches thick to 94 beetles for phloem 0.23 inches thick. Brood production ranged from about 3 beetles for 10 inches of egg gallery to 130 beetles for 174 inches of egg gallery. When food supply limited production, numbers of emerging brood adults increased linearly with phloem thickness. When food supply did not limit production, numbers of emerging brood adults increased exponentially with an increase in inches of egg gallery.

Laboratory studies were conducted during the winters of 1968 and 1969 to investigate: (1) the relation between phloem thickness of lodgepole pine, *Pinus contorta* Douglas, and brood production of the mountain pine beetle, *Dendroctonus ponderosae* Hopkins; and (2) the relation between number of inches of egg gallery and brood production. Recent studies indicated that epidemic populations are dependent upon large lodgepole pine having thick phloem. It has been shown (Reid 1963, Cole and Amman 1969) that numbers of emerging beetles usually increased with size of tree, based not only on the greater surface area of the trees but also on a unit area of bark surface. It was further demonstrated (Cole and Amman 1969) that the beetle preferred trees of large diameter during any given year as well as over the life of an infestation. That numbers of beetles were more closely related to total bark thickness than to diameter of tree was reported previously, and it was hypothesized that the critical factor was thickness of phloem (Amman 1969).

MATERIALS AND METHODS.—*Test I*.—Ten uninfested lodgepole pine trees varying in DBH from 8 to 16 in. were selected for a wide range of phloem thicknesses. These trees were cut on the Wasatch National Forest, south of Evanston, Wyo., in January 1968. Five 18-in. bolts were removed from each tree—the 1st bolt was taken at breast height and the others at 5-ft intervals up the trunk. One slab, 6×12 in. and about 2 in. thick, was cut from each bolt, resulting in a total of 50 slabs for the test. Phloem thickness was measured to the nearest 0.01 in. at the midpoint on each side of the slab; the average of the 4 measurements was used as a measure of phloem thickness for the slab. The edges and all exposed wood of each slab were waxed to prevent rapid moisture loss.

The methods of Cole and Weenig (1967), with minor changes, were used to infest the slabs with beetles. At the base of each slab, 8 circular pieces of bark were removed with a no. 3 cork punch. These depressions were equally spaced across the 6-in. base, and they formed the attack chambers for the female mountain pine beetles obtained upon emergence from bolts cut from naturally infested trees on the Teton National Forest. The beetles were sexed by the method recommended by Lyon (1958), which was based on differences in morphology of the 7th abdominal tergum, first noted by Hopkins (1909). The beetles then were cleansed of mites because some species are predaceous. The female beetles were placed in the attack chambers and covered with a no. 000 gelatin capsule. The female was allowed 24 hr to initiate attack and start egg-gallery construction, then the capsule was removed, and bark (boring frass) that had been pushed into the attack chamber by the beetle was extracted. A male then was placed in the chamber, and the capsule was replaced. If the female failed to start gallery construction, an alternate female was placed in the chamber and the entire procedure was repeated. Each slab

[1] Coleoptera: Scolytidae.
[2] Received for publication Mar. 22, 1971.
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was placed in a vertical position so that the female could construct the usual vertical egg gallery.

Two weeks after males were placed in chambers, the slabs were radiographed using techniques presented earlier (Amman and Rasmussen 1969). From these radiographs, gallery construction was determined. If total egg gallery was less than 20 in., the slab was replaced because full utilization of phloem by developing larvae was desired. Another slab was obtained from the same bolt as the original and infested with fresh beetles. Eleven of the original 50 slabs were replaced in this manner.

The slabs were held at room temperatures, between 20° and 26°C, for 8 weeks. At the end of this period, boring frass was being expelled during maturation feeding of the teneral adults. The slabs then were placed in galvanized cans with tight-fitting lids. Emerging beetles were collected and counted daily.

Test II.—This test was designed primarily to investigate the effect of number of inches of egg gallery on brood production. The number of inches of egg gallery, hence number of eggs and ultimately number of larvae, would determine the amount of phloem utilized.

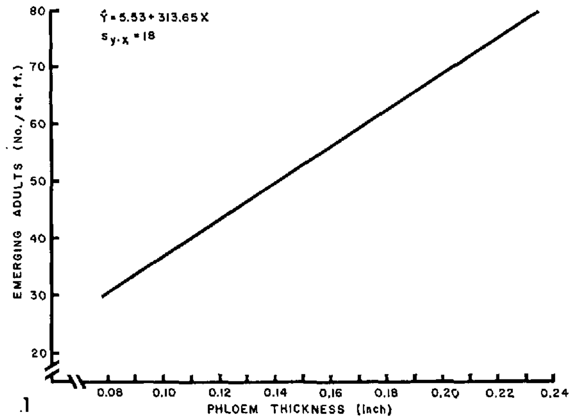
Three lodgepole pine trees were obtained during late fall 1968 from each of 3 National Forests: the Wasatch south of Evanston; the Caribou near Soda Springs, Idaho; and the Teton near Jackson, Wyo. The trees ranged from 18 to 23 in. DBH, and phloem thickness ranged from 0.16 to 0.26 in. Billets were removed from the base of the trunk of each felled tree and taken to the laboratory. In January 1969, 9 slabs 6×12 in. were cut from billets obtained from each tree, giving a total of 81 slabs for the test. The procedures of slab care, beetle introduction, beetle collection, and counting were the same as those for the 1st test. For this test it was necessary to obtain a wide range in number of inches of egg gallery; thus, all original slabs were retained regardless of how much egg gallery was constructed.

Analysis.—The numbers of emerging beetles and inches of egg gallery were expanded to represent numbers per square foot. Regression analysis was used to analyze the data from both tests.

RESULTS.—*Test I.*—In Test I the intent was to obtain full utilization of phloem; therefore, a linear relation between numbers of emerging brood adults and phloem thickness was expected. This expectation held true over the range of phloem thicknesses examined (0.09–0.23 in.) (Fig. 1). Emergence ranged from 16 beetles for phloem 0.09 in. thick to 94 beetles for phloem 0.23 in. thick. The number of inches of egg gallery ranged from 50 to $202/ft^2$ and resulted in nearly complete phloem utilization. The relation of emerging brood adults to phloem thickness, and the relation of brood adults to gallery inches were determined in individual regressions. Phloem thickness accounted for 25% of the variance (R^2) in emerging adults, but the number of inches of egg gallery accounted for less than 1% of the variance. The interaction of phloem thickness and gallery inches accounted for no more variance than phloem thickness alone.

It should be remembered that slabs with less than 20 in. of egg gallery were replaced in this test. This artificial restriction in range of inches of egg gallery is at least partly responsible for the low R^2.

Test II.—In Test II, the primary intent was to



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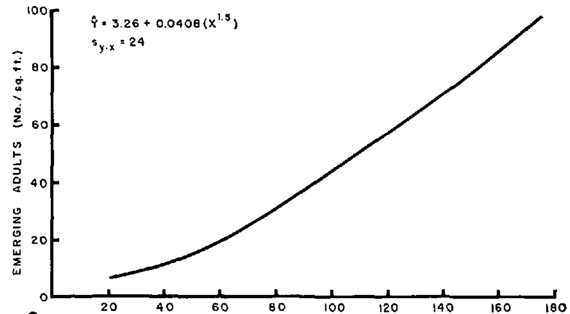

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FIG. 1, 2.—Relation between number of emerging brood adults of the mountain pine beetle and thickness of lodgepole pine phloem (Fig. 1) and inches of egg gallery made by parent adults (Fig. 2).

establish the relation between production of beetles and gallery inches in the absence of the phloem-thickness effect; therefore, only slabs having thick phloem (0.16–0.26 in. thick) were selected.

Inches of egg gallery, which ranged from 10 to $174/ft^2$, explained 44% of the variance in emerging brood adults which ranged from 0 to $130/ft^2$. Within the range of phloem thicknesses used in this study, the effect of phloem was unimportant and explained only 6% of the variance. We can conclude that phloem was utilized incompletely. This conclusion is supported by information shown in Fig. 2, that the slab with the most gallery also had the greatest emergence of brood adults. However, reductions in brood production are known to occur where the numbers of egg gallery inches are excessive (Cole 1962, Knight 1960, McMullen and Atkins 1961, Reid 1963).

Although phloem thickness and number of egg gallery inches were important factors affecting brood production, considerable variance in brood production remains unexplained. This is attributable to experimental error and to unmeasured variables. Two additional variables affecting brood production are the proportion of the phloem layer occupied by pitch pockets and the distribution of egg gallery within the phloem. Some bark contained many large pitch pockets that were avoided by the feeding larvae. Although distribution of gallery was not investigated, an even distribution would probably result in maximum usage of phloem and maximum production of beetles.

DISCUSSION.—In this study, numbers of emerging brood adults of the mountain pine beetle increased linearly with phloem thickness of lodgepole pine when food supply limited brood production. Although the relation between brood production and phloem thickness was not very strong ($R^2 = 0.25$), phloem thickness is the most important single factor affecting brood production of the mountain pine beetle, based on this and past work. These findings have important implications for the future of lodgepole pine management (see Roe and Amman 1970).

Emergence of brood adults increased exponentially with an increase in inches of egg gallery ($R^2 = 0.44$) when food supply was not limited. Therefore, we might expect number of inches of egg gallery to explain a greater proportion of the variance in brood production in trees having thick phloem than in trees having thin phloem.

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Effects of Treating Adult Codling Moth[1] with Sterilizing and Substerilizing Doses of Gamma Irradiation in a Low-Temperature Environment[2]

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ABSTRACT

Unfed adult *Laspeyresia pomonella* (L.) treated in a 3.0°±2°C environment with 15 and higher krad of gamma irradiation lived 1–7 days longer than untreated moths. Eggs per female declined as the dose to either sex increased, and the reduction was greater when females only were treated or when treated females were paired with treated males. Males irradiated with 30 krad and paired with untreated females showed over 99.0% sterility. Three apparently normal F_1 male adults resulted from 120 pairing between untreated females and males treated with 30 krad. An inverse relationship existed between the longevity of untreated females and eggs per female, and the increases in longevity of treated females proved to be a function of both dose of irradiation and oviposition.

Proverbs and Newton (1962a) and Hathaway (1966) reported an effective sterilizing dose of ca. 40–45 krad of gamma irradiation for the adult codling moth, *Laspeyresia pomonella* (L.). In both studies, the moths were immobilized during irradiation by CO_2; however, we (White et al. 1970) showed that immobilization at ca. 3.0°C was less deleterious than immobilization with CO_2. We also reported on the effects on longevity and oviposition of treatment of the codling moth at doses of 25, 30, 35, 40, and 45 krad. We have not previously reported the effects of irradiating codling moths at 10, 15, 20, or 50 krad; also, we have not previously reported on effects of the doses on mortality in the developmental stages or on F_1 and F_2 progeny.

Reported here are results of 2 tests made at the Arid Areas Deciduous Fruit Insects Investigations Laboratory at Yakima, Wash., in 1969 in which adult moths were irradiated in an environment of 3°±2°C at doses of 0, 10, 15, 20, 25, 40, and 50 krad. Effects on longevity, stage mortality, mating, oviposition, egg hatch and F_1 and F_2 survival and reproduction were recorded.

METHODS AND MATERIALS.—*Rearing Procedures.*—All moths were from our laboratory colony and were reared on thinning apples at average conditions of ca. 26°C, 60–70% RH, and a 16-hr photophase (Hamilton and Hathaway 1966). Cardboard strips (A flute size, 1.3 cm wide) were placed over apples as pupation sites for emerging larvae. When the strips were filled with larvae, they were collected and cut into individual flutes. Each flute containing a pupa was then placed in a stoppered 4.5-mm glass vial (so we

[1] Lepidoptera: Olethreutidae.
[2] Mention of a proprietary product does not constitute endorsement by the USDA. Received for publication Apr. 1, 1971.