Sounds of DOUGLAS FIR BEETLE ACTIVITY

. . . Recorded and Interpreted
. . . Equipment Techniques

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August 1958

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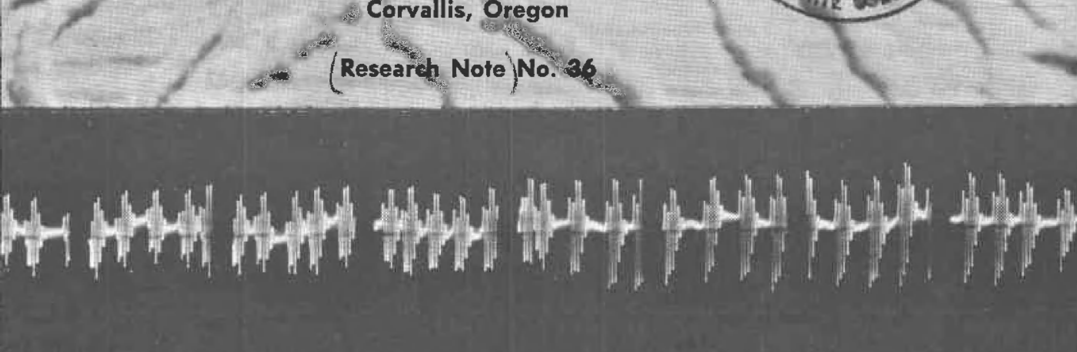
Research Note No. 36



Forest Lands Research Center

. . . Its Purpose

Develop the full potential of Oregon's timber resource by:

increasing productiveness of forest lands with improved forest practices.

improving timber quality through intensified management and superior tree selection.

reducing losses from fire, insects, and diseases—thus saving timber for products and jobs.

Keep development of the forest resource in harmony with development of other Oregon resources.

. . . Its Current Program

Seed production, collection, extraction, cleaning, storage, and germination.

Seedling production, establishment, and survival for new forests.

Growth and development of trees, quality of growth, and methods of thinning and harvesting to grow improved trees.

Study of forest fire behavior and fire weather to prevent fires.

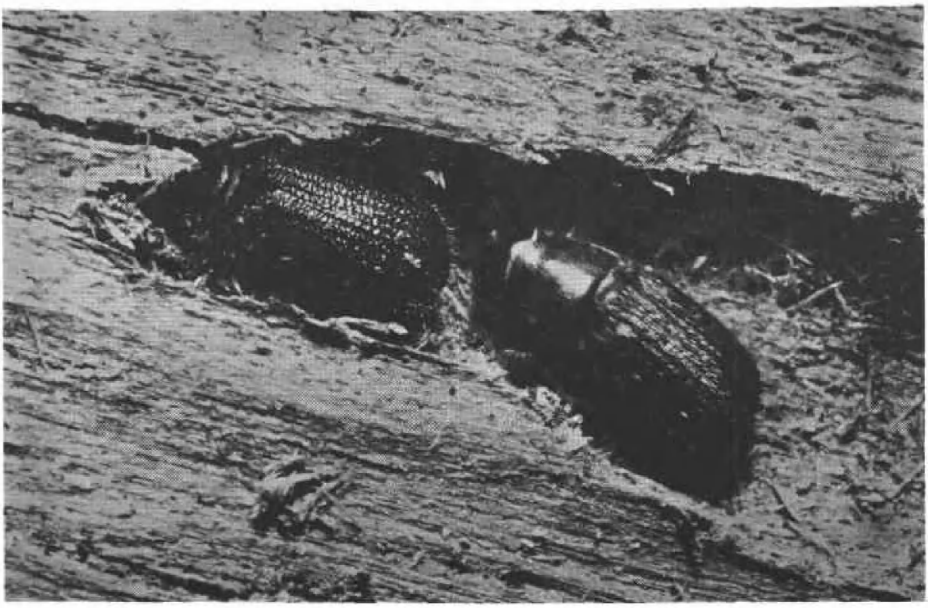
Insect pests and their control, to save trees.

Disease control and prevention in Oregon forests.

Mammal damage and the controls to help regrowth.

Soils and their relationship to growth.

Development of improved forests through selection and breeding.



Douglas fir beetles in gallery.

Summary

Although Douglas fir beetles cause great losses to the lumber industry in Oregon, little is known about why they attack certain trees or when it is economically wise for forest owners to use controls or change logging schedules to harvest infested trees.

One reason it is difficult to learn more about these beetles is that they live beneath tree bark and cannot be observed without being disturbed.

In an effort to find out more about the beetles in their natural habitat, amplifiers and other equipment were used in this study to listen to the insect's noises, record the sounds, and photograph the sound patterns. Chewing, chirping, and other noises were found to indicate the amount of activity and degree of infestation.

Results of this study indicate that if, through use of sound amplification, forest owners and lumber manufacturers could know more accurately what is taking place inside a log or a piece of lumber, they could manage their harvesting more economically.

To check the accuracy of amplifying techniques, the research entomologist making this study asked for assistance of electrical engineers at Oregon State College. The two engineers who worked on the problem found that in previous studies, made elsewhere, in which insect noises were recorded, little or no account had been taken of the sounds and patterns made by the microphone itself, apart from those made by the insects.

The engineers believe listening to sounds of beetle activity with amplifiers can be of economic value, and they recommend further improvement of techniques.

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The study of detailed behavior of forest insects under bark or in wood is hindered by the limitations of visual techniques. During a recent study of the natural microclimate of breeding Douglas fir beetles (*Dendroctonus pseudotsugae* Hopkins) and its effect upon brood development, need became apparent for a better method of observing some details of beetle behavior without altering the natural host-parasite complex. The frequency, rate, and duration of excavation activity in direct response to temperature, temperature changes, and related factors cannot be determined in individual pairs throughout their breeding cycle by the usual methods of measurement. This is a report of the initial progress made in developing a supplementary observation method.

Efficient controls against the Douglas fir beetle are apt to be difficult, if not impossible, to develop economically without thorough knowledge of the insect's fundamental behavior under natural conditions. Little useful information seems to have been published concerning details of the beetle's behavior under conditions not materially altered for purposes of investigation, and almost nothing of importance is strictly known about natural cause and effect in its immediate responses. What attracts and repels the Douglas fir beetle, for example, is not fully understood. It is not known certainly why the beetle in an epidemic selects certain living, standing trees for attack and rejects other trees. The chemical nature of a host is perhaps the cause of selection, but other possible contributing factors must be considered. One of these may be sounds made by the adult beetles.

No reports have been found on the real function of the sound-producing mechanism (chirping and stridulation) of the genus. This factor might be one which Person* and his colleagues quite naturally overlooked.

Sounds produced by individuals of the genus under favorable conditions are audible to the normal human ear, but they are too weak to be analyzed without amplification. The technique of amplifying and recording sounds produced by the beetle's subcortical activities and determining the significance of these records might provide valuable information about the species. The technique certainly is essential to longtime observation of an individual pair's behavior under bark.

* 1931—Person, H. L. Theory in Explanation of the Selection of Certain Trees by the Western Pine Beetle. Journal of Forestry 29:696-699.

Use of Sound Amplification In Other Biological Work

The use of electronic audio amplification in biological work is well established. Some such work with insects is described in the literature. Two of the more pertinent reports are those of Pierce[†] and Ossiannilsson[§]. Pierce, like many of the earlier workers dealt with aerial sounds produced mostly by some of the Orthoptera. Ossiannilsson studied members of the Homoptera. The phenomenon of sound production among insects is so commonplace as to warrant further study in relation to problems of economic entomology.

Preliminary Testing of Sound Equipment

Figure 1. Contact microphone in place on section of log.

Early in the field season of 1956, an Ampex Model 601, portable full track recorder with a matching amplifier and speaker and a Fisher Type 80-C Master audio control preamplifier were employed. The speaker had a frequency response of from 30 to 15,000 cycles at a tape speed of $7\frac{1}{2}$ inches per second. High fidelity, long-playing tape was used for recording. An Electrovoice, crystal type contact microphone, Model 805, was used for all monitoring and recording in the 1956 work. Earphones were used for monitoring while recording and for direct listening when not recording. The equipment was built to operate at 110 volts A.C.

A log section containing breeding beetles was obtained June 8, 1956, from a felled tree on a study plot. The plot was located at 2,700 feet on the Corvallis watershed, Marys Peak, Benton County, Oregon. The tree had been felled April 28 and heavily attacked May 15, 1956, but the attacks were still incipient because of subsequent cold, cloudy weather.

The log section was set up at room temperature, which usually was about 70°F. The contact microphone was spotted near mounds of boring dust

An initial experiment explored the potential usefulness of a sound amplifier and sound recording system of the tape recorder type in the study of bark beetle behavior. The objectives were: to determine the effectiveness of the method and equipment; to learn the nature and direct causes of the sounds produced by the beetles; and to learn the frequency or rhythm, relative intensities, and duration of their sound producing activities.

† 1948—Pierce, George W. *The Songs of Insects.* Harvard University Press, Cambridge, Mass.
§ 1949—Ossiannilsson, Frej. *Insect Drummers.* Lund, Berlinski.

until a well defined sound was heard. The outer bark was smoothed at that point and the microphone secured by means of large rubber bands encompassing the log section. Minor adjustments of the microphone were then made until the clearest signal was obtained.

Preliminary Observations

Although the primary objective was to test the effectiveness of a tape recorder for this work, some biological observations were made.

An example of the nature of the observations is shown in excerpts from detailed notes made during these experiments:

June 8, 1956
p.m. PST

- 9:10 Rhythmic, cricket-like chirping alternating and sometimes occurring simultaneously with irregular, sharp, staccato clicking or scratching noises.
- 9:23 Still the same sounds, both intermittent and simultaneous.
- 9:38 All sounds have just stopped.
- 9:48 Beetles silent for previous 10 minutes.
- 9:55 Very slight, occasional single scratch, probably the female excavating.
- 10:19 Vigorous chewing resumed.
- 10:28 Chewing recorded during the previous three minutes.

To start gathering data on the distribution and degree of sound-producing activity during any 24-hour day, the following observations were made:

June 9, 1956
a.m. PST

- 4:20 Room temperature 70°F.
- 4:30 No sound of activity during previous 10 minutes.
- 4:35 Chewing sounds for past 20 seconds, but not vigorous.
- 4:45 Occasional single click as of chewing.
- 4:55 Occasional click; no other activity heard.
- 5:00 Stopped monitoring.

Visual checks, made later, proved the accuracy of activities identified by amplified sound phenomena.

June 9, 1956
p.m. PST

- 10:20 Room temperature 72°F. Heard active beetles in gallery at lower points on the log than last night
- 10:40 Stridulation like the high-pitched croaking of a small tree frog as more distant chewing goes on.
- 10:45 Bark dust has been pitched out of the entrance hole of this gallery steadily for the two days the log has been set upright. Bark dust is now ejected from top, or first ventilation hole, a little below locus of chewing sounds, not far from the entrance hole.
- 10:55 Light on. Chewing sounds and another sound definitely recorded. This other, or third type of sound, is a faint swishing and seems to accompany removal of bark dust to the excavation hole and its ejection. The chirping, or stridulation, does not continue during the simultaneous sounds of chewing and bark dust removal.

11:10 Chewing very active. A beetle at another point just pitched a small mass of dust out of a hole. The dust was pushed out of the hole in a series of shoves, the last three of which brought the beetle's head to view. On clearing the hole the beetle disappeared instantly. It pitched the dust ahead by upthrusts of the head and pronotum. The boring-dust mass swelled almost instantly to about twice its size when ejected from the so-called ventilation hole. (This beetle is the first direct evidence of *Dendroctonus* beetles in the log. Its activity did not interfere with recording of the sounds occurring at the microphone locus.)

11:20 Stopped recording. Beetles still active.

Prior to the beetle's appearance at 11:10 p.m. the Douglas fir beetles were merely assumed to be in the log section. Another experiment was initiated for audio-visual association and verification of the direct causes of typical sounds so far observed.

Correlation of Visual and Audio Observations

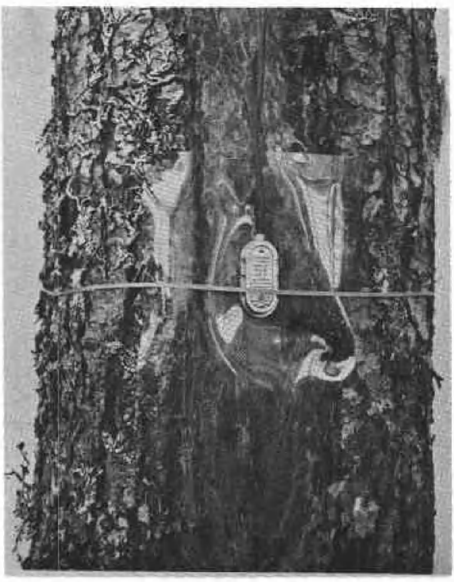

Figure 2. Correlation of visual and audio observations. Contact microphone is placed on clear plastic which covers exposed galleries.

On June 19, 1956, a new log section was cut from the same tree as before and prepared for study in the field laboratory at Alsea Camp. The low temperatures at the field plot had retarded beetle development so the insects in the new log section had not progressed significantly beyond the stage of study of the first group.

To prepare the log section for coordinating audio and visual identification, a gallery was exposed sufficiently to permit the watching of the insects while listening to the sounds. This was done by selecting the locus of a loud signal, and then carefully removing the outer bark at the estimated location of the loudest sound. A microphone usually can be located quite accurately on the first trial.

The outer (or ceiling) one-third of the gallery wall was removed and a working pair of beetles brought to view without injury. The log section was placed top end up with the beetle pair facing upward near the front of the gallery. This vertical orientation of log and beetles did not cause them to change direction or the form of gallery construction although the log had been in a horizontal position when attacked. The bark area around the partially exposed gallery was smoothed, and a sheet of 1/32-inch plastic was fitted over the surface and stapled well back from the margin of the gallery.

Before and after application of the plastic cover, the beetles were examined, *in situ,* for possible injuries. A magnifying hand lens was used for this purpose.

At first the contact microphone was placed against the bark just above the upper end of the gallery where the female had been excavating. Later, it was placed directly on the plastic cover to the right side of the beetles. The plastic worked well as a soundboard. Two large rubber bands, as before, held the microphone in place and permitted some shifting for better signals without complete removal. To record air temperature at the bark surface, an extension element of a 24-hour recording thermograph was inserted under the rubber bands and against the bark at the locus of activity. No difference in temperature was recorded when the element was placed against the plastic beside the beetles.

Response of beetles

The activity of the pair was inhibited during this preparation. On first exposure the female backed down from the position at the head of the gallery where she had been making gnawing-cracking sounds. (Designation of sex in this report is based on the assumption that the female is invariably the egg gallery pioneer.) She had looked about, waved her antennae in different directions as she turned her head and pronotum, shifted position by short, abrupt leg movements sideways, backward and forward, and showed general irresolution. The male behind her hesitated in a similar way.

After a few minutes of quiet, however, some irregular chirping commenced, and there occurred what resembled an excited conference by chirping and gesture during which the male moved forward and upward and repeatedly nudged the female in her declivity with his head. In this activity he used upward and forward movements of head and pronotum similar to those observed when the male in the first study was ejecting boring dust from the gallery. One or two such pushes were needed each time to make the female move forward a bit, with seeming unwillingness, until she reached the place where she had been excavating. This behaviour was observed and recorded between 8:45 p.m. and 9:12 p.m., at a 69°F. air temperature at the bark surface by the gallery.

Further notes

June 19, 1956
p.m. PST

9:12 Stridulation almost continuous, but much of it weak.

9:49 Excellent stridulation.

9:50 Stridulation ceased.

9:58-
10:11 Chewing continuous during this time.

10:11 Chewing becoming more rapid after an electric heater was directed on microphone area from a distance of about 30 inches until the temperature at the microphone location showed 74.5° F. The female seems to strip or shred the wood fibers until they can be broken or snipped off. When this recording was started the male had his head pushed against the female's declivity.

10:16 Brief stridulation. Both beetles are circling around the fore-end of the gallery.

10:23-
10:26 The chirping rhythm is alternately slow and rapid, but not with equal intervals of time.

10:45 Distinct chewing. The male is transporting and packing boring dust into the left juncture of bark and plastic at a point about 2½ inches back from the female.

11:04 Room temperature at log surface, 73°F. Excellent stridulation.

11:10 Moved microphone forward. Head of male touching female declivity but female is a body length from upper end of gallery. Marked positions with red pencil, pressure of which on plastic window caused them both to move upward, and female commenced very loud and vigorous chewing. (Bright light seems not to inhibit activity.) Dorso-ventral pumping motions of the pronota of both beetles are occurring simultaneously except for two brief periods during which one and then the other performed with the so-called stridulation sounds occurring in unison with the pronotal movements.

11:26 Started recording with new tape while watching.

11:32 Stopped tape. Wiped red crayon from plastic for better view. Beetles stopped activity.

11:36 Started tape.

11:42 Stopped recording. Beetles very quiet. The cricket-like chirps seemed at the time to result from an up and down movement of the pronotum and head of either one. This may affect the greater volume of sound produced at times by strengthening the abdominal-elytral friction, or it may be related to production of sound by other parts of the body. Abdominal-pronotal or head-pronotal functions should not be overlooked.

11:55 Chirping or rubbing sound.

Mid-
night Clear recurring sounds like low squeaks.

June 20, 1956

a.m. PST

12:05 Body movements of both are now slight to considerable.

12:10 Sounds now infrequent.

12:18 Chewing and chirping more active.

12:28 Still actively chewing and chirping.

12:42 Stridulation just stopped and now more vigorous chipping-chewing followed for a brief time by mixed sounds of both types.

12:52 Both chewing and chirping ing sounds vigorous. Watched another beetle in another gallery "back-end" a bit of boring dust out a cleanout hole, using its elytral declivity as a scoop.

1:05 End of tape.

Monitoring and recording were resumed again in the evening.

p.m. PST

7:35 76°F. Excellent activity. Record on tape; start 5:08, stop 7:40, start 7:44, stop 7:46, start 7:56, stop 7:58, start 8:16, stop 8:18, start 8:23, stop 8:51 p.m. Each start and each stop signifies the beginning and ending of sound producing activity.

10:35 Beetles have bored approximately 1 to $1\frac{1}{2}$ inches forward and upward, out of sight since last night.

11:40 Stopped observing.

Field Test

Figure 3. Sound amplification equipment on log at Marys Peak.

In the field, an old ATR Model 6 H S H Inverter was connected to the 6 volt DC car battery and the car generator kept in operation. The inverter was connected to the tape recorder amplifier by a rubber sheathed cable of sufficient length to reach from car to recorder position on the log. The distance from the car helped reduce airborne inverter noise. A dynamotor type of converter for reduction of inverter background noise was preferred but was not available.

On June 21 the recording equipment was moved to the study plot in the field and set up 20 feet from the butt on the down tree from which the previously used sections were taken. From 12:25 p.m. to 3:20 p.m. typical sound phenomena from the beetles were heard, but as the air cooled, beetle activity declined. By 3:20 p.m. there was not enough activity to be worth recording. The recordings made at this time proved to have picked up considerable noise. Need for field equipment to decrease background noise was evident.

Technique Refinement

In June, 1957, a similar tape recorder as previously described was taken with log samples to the Electrical Engineering Department at Oregon State College. Engineers in the department contributed preliminary work in improving amplifier and microphone performances. Photographic records were made for analysis of sound characteristics shown on the oscilloscope. The commercial high-fidelity amplifiers were not designed for such specialized application and included some expensive features unnecessary for this purpose. However, the laboratory equipment provided by the Electrical Engineering Department showed what can be done toward satisfactory refinement and fabrication of various special equipment.

Observations of Motor Phenomena In Relation to Chirping

It was of special interest that during the electrical engineers' work a chirping session of a beetle pair was recorded, and it was agreed that both beetles took part. While the male was chirping alone the female was continually gnawing. The sound of gnawing suddenly ceased and a much more vigorous chirping began in a descending scale with different pitch and tempo. For an instant, it seemed that two beetles were chirping at the same time, but it could be that two sound-producing mechanisms on one of the pair were operating simultaneously. However, the frequency of chirps and tonal qualities of the respective sounds in this apparent duet sounded distinctly different. The apparent mood of expression also seemed distinct.

The possibility of the second chirping coming from another beetle in another gallery more distant from the microphone was discarded in this case. There were early instar larvae present in the gallery so the possibility of the beetles being both males was rejected. Ventriloquial attributes in the male were considered improbable. Echoes and harmonics were also improbable. In the audio-visual study of the previous year both beetles in the gallery were seen to manifest similar pronotal movements when chirping was recorded. Photography now is being used to study this part of the recording. Further work on this phenomenon should include morphological examination.

Possible Technique Applications

The previous paragraphs are included in this report to suggest one of the many behavior problems which sound amplifying technique could help solve. Its use should facilitate valid research and thus help fill the gaps in knowledge. Without development of this, or a similar technique, some problems of cryptic insect behavior might continue unsolved indefinitely.

Advantages of this method for studying activities of subcortical insects should justify considerable expense in developing and refining specific equipment.

Although interference is a problem in such use of high-fidelity equipment, it is possible to reduce satisfactorily most extraneous sound. Some of the expensive circuit designs of commercial tape recorders are unnecessary for this special application.

Whatever the imperfections of equipment used in these experiments, the method's value as a means of making biological assessments of subcortical insects without altering their environment is evident.

The technique also might be modified for industrial use. Commercial detection of wood-boring insects in green lumber ready to be marketed is one such possibility. The initial expense of developing such a device would be considerable. It could, however, pay for itself by preventing the not uncommon rejection of lumber shipments on evidence of wood-boring insects, and by eliminating in some cases the cost of wood treatment at the mill.

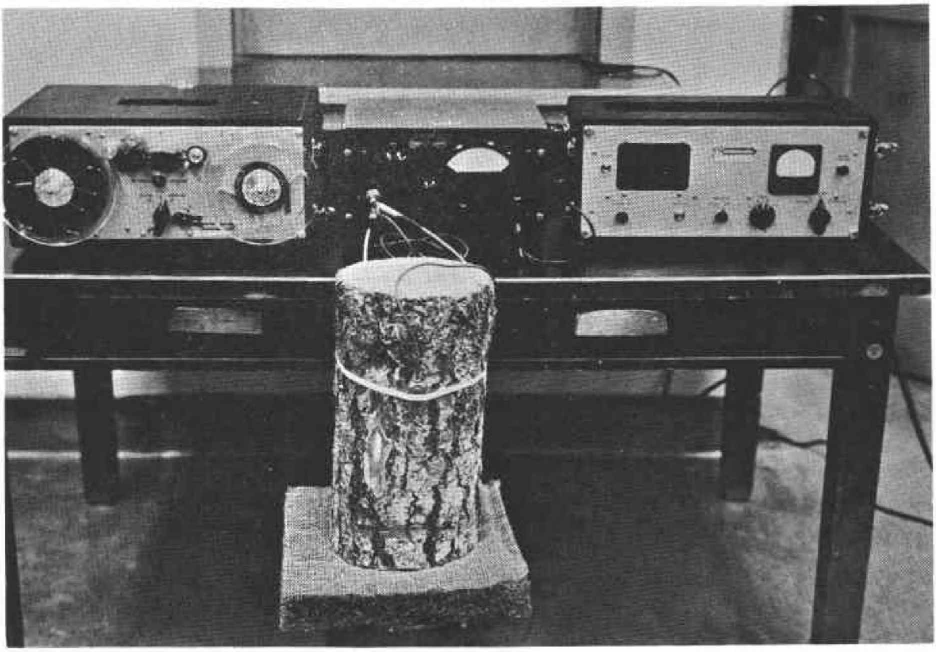

Figure 4. Contact microphone installation in laboratory.

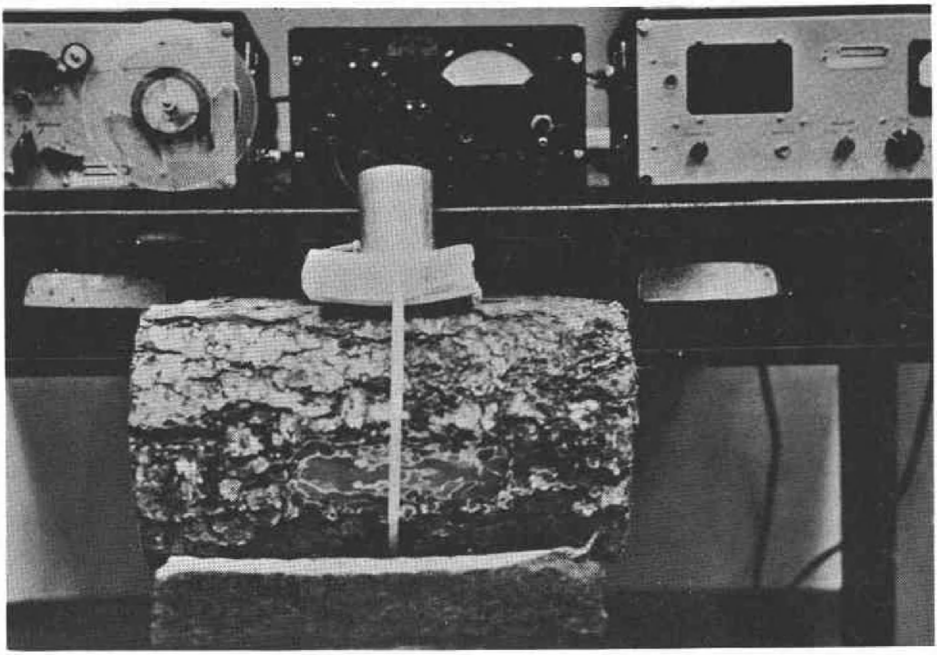

Figure 5. Diaphragm microphone mounting.

Sounds of DOUGLAS FIR BEETLE ACTIVITY

. . . Equipment Techniques

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The desirability of exploiting sound phenomena in the study of subcortical insects has been established in the accompanying treatise. This paper will explore some of the technological aspects of this process, describe the signals that must be accommodated, and also offer tentative specifications for equipment required to achieve a reasonable degree of success in this approach, and point out areas in which further study is needed.

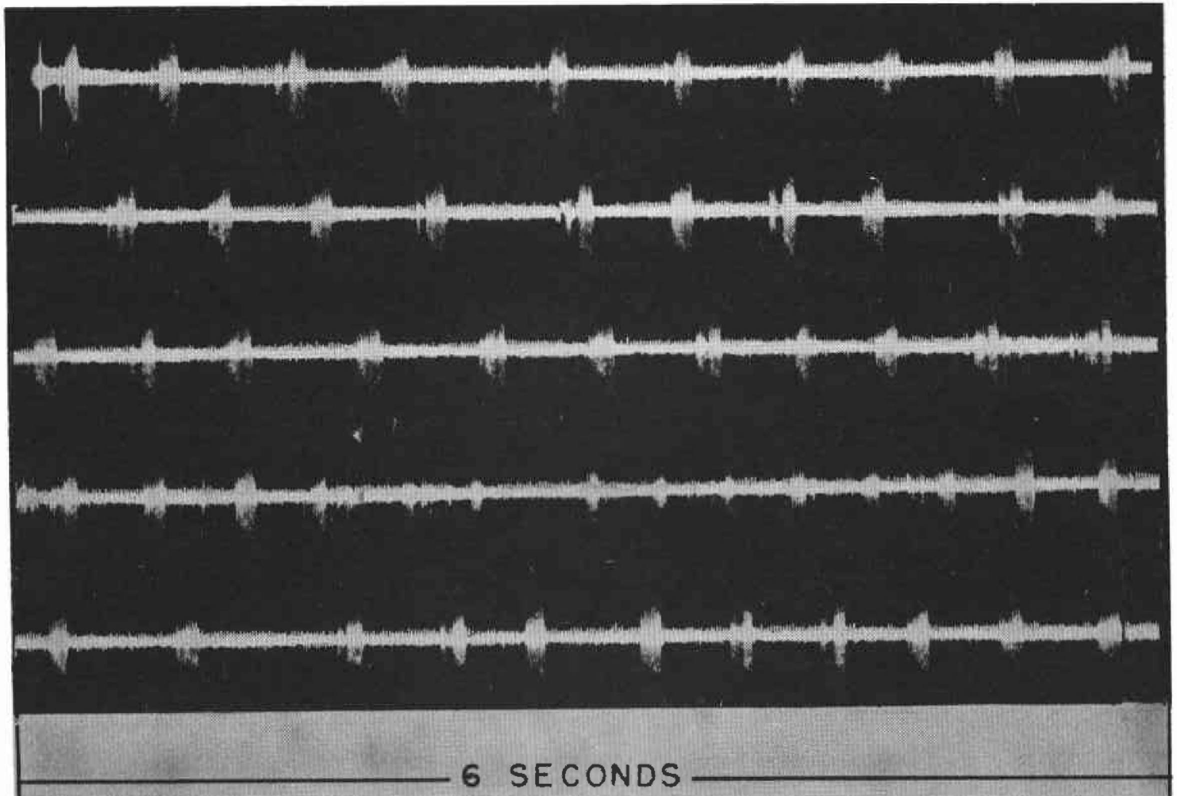
Characteristic Stridulation

Some knowledge of the characteristic sound waveforms of the insect is necessary for an appreciation of the details of the apparatus investigated. While the following description is based on a limited number of observations under relatively uncontrolled and perhaps unnatural conditions, the general pattern is believed to be sufficiently typical to form the basis for the selection of equipment. Experiments leading to this belief will be described in detail in a later section.

The sound made by the insect consists of a succession of chirps usually occurring at a reasonably uniform rate in the range of one or two chirps per second. Each chirp is made up of a series of bursts, believed to be separate and distinct, at a rate of 400 to 500 bursts per second. Both amplitude and frequency of the bursts may change during the progress of the chirp, lending each chirp some measure of individuality.

This pattern is illustrated in figures 6 and 7. Figure 6 consists of approximately 30 seconds of the song as recorded first on magnetic tape, then on film using a moving film technique of recording a cathoderay tube presentation. Figure 7 is a similar recording of a single chirp showing the bursts of which it is comprised. Background noise, largely 60 cycle per second hum, is evident in the small regular continuous oscillation at the center of the trace.

The tremendous range in time scale involved in these and following illustrations must be emphasized to insure a full appreciation of the scope of the sound pattern. This range is several thousand to one, from many seconds included in figure 6, to a few milliseconds in figures 8c and 8d. The cyclic


6 SECONDS

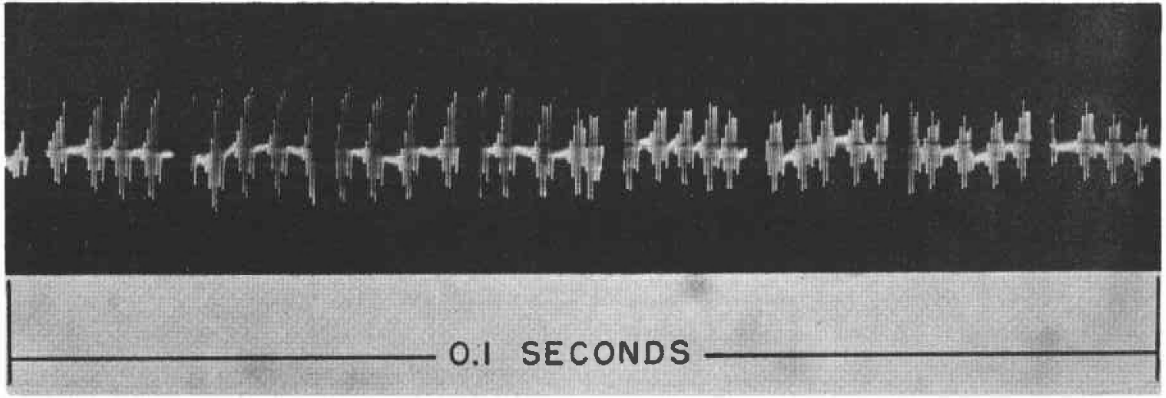


Figure 6. (top). Approximately 30 seconds of a typical song of the Douglas fir bark beetle. Note the irregular rate of occurrence (one or two per second) and the variation in character of individual chirps. Time progresses from the left to right and down through successive lines. The continuous band through the center of the record represents stray noise in the pickup, recording, and reproducing systems.

Figure 7. (bottom). Details of a typical single chirp, showing the rapid succession of independent bursts comprising the chirp. Note particularly the time scale as compared to that in figure 6. Blanks in the record arise from the mode of operation of the oscilloscope.

nature of both chirps and bursts may easily lead to confusion if the vast difference in time is not recognized.

The peak sound pressure at the microphone is estimated to be in the order of 40 db (decibels) above 0.0002 dynes per square centimenter, or about 100 times the nominal threshold of human hearing. This level is still so low as to be barely audible to a person with good hearing only a few feet distant in very quiet surroundings.

Early Experiments

The low sound level produced by the insect relative to the inherent noise level in the equipment used in the initial experiments seriously limited the usefulness of the recordings obtained. When this problem was brought to the attention of the authors, a solution was sought in two main areas: improved microphone sensitivity (at the expense of increasing pickup of noise from the surroundings); and improved noise characteristic of the microphone amplifier. The latter is particularly important since peak microphone output may be only one-tenth millivolt and a few microvolts of noise can obscure essential detail in the sound pattern.

Direct listening to beetle activity is a valuable technique, but some method of recording is essential to permit detailed study of the sound patterns. The magnetic tape recorder seems ideally adapted to this purpose. A good recorder should have a self-noise level at least 50 db below its useful output. This, however, is based on a relatively large input signal, on the order of hundreds of millivolts, and the microphone signal must be amplified several thousandfold, with correspondingly low noise to fully exploit the quality of the tape recorder.

Amplifiers

A commercial high-fidelity-type preamplifier was briefly checked as a microphone amplifier and found unsatisfactory in both gain and noise level. A General Radio type 1231-A Null Detector Amplifier was substituted with good results and subsequently has been used exclusively. The particular amplifier used has a measured gain of 75 db and a noise level referred to the input of about 20 microvolts.

No other amplifiers have been investigated, but little difficulty should be experienced in obtaining either a commercial or custom amplifier capable of meeting or exceeding the performance of the General Radio instrument.

Microphones

The initial tests were made using an Electrovoice Model 805 crystal contact mitrophone. This device is actuated primarily by vibrations transmitted through the wood and bark of the log specimen. In an effort to obtain greater sensitivity and to study the character of airborne sounds, a microphone unit was assembled using a diaphragm-type crystal microphone cartridge. The microphone cartridge was mounted in sponge rubber in a heavy aluminum housing to exclude as much extraneous sound as possible. In use this mount is placed over a hole in a sponge rubber pad and the assembly strapped over an area of the log specimen showing beetle activity.

Observations of sound waveforms as picked up by both microphones were made using a cathode ray oscilloscope both directly and from tape recordings. It was noted that the fine structure of individual bursts within each chirp was dependent on the microphone in use, and a difference in the quality of the sound could be detected. Further observation, particularly of the output of the diaphragm microphone, revealed a damped ringing, a characteristic of a resonant mechanical system. While this phenomenon might be attributed to the different transmission paths between insect and microphones, it was concluded that microphone characteristics were more likely responsible and experiments were formulated to resolve the question.

Microphone tests

The nature of observed waveforms suggests that each burst arises from a signal approaching a single abrupt impulse of sound pressure and that the ringing is the characteristic response of the microphone to such an impulse. For the contact microphone this was originally checked by the crude expedient of dropping a small lead shot on the face of the microphone in a glancing trajectory. The resulting waveform was so remarkably similar to the burst observed in the chirp that more extensive tests were undertaken.

Sound impulses of known waveform are extremely difficult to produce, but analogous electrostatic forces may be generated and checked with comparative ease. This is known as an "electrostatic actuator" technique, and while the details are beyond the scope of this paper, they may be found in the literature.‖ Apparatus was constructed to test both the diaphragm microphone and the contact microphone, both for impulse response and frequency response. In addition, the approximate sensitivity of the diaphragm microphone was measured and found to be 40-45 db below 1 volt per dyne/cm^2.

Sample recordings with the two microphones are compared with each other and with the impulse tests in figure 8. Note the differences between the recording with the contact microphone in figure 8a and that with the diaphragm microphone in figure 8b. These illustrations have nearly identical time scales (about 16 milliseconds from left to right) and depict random samples of typical small groups of bursts within a succession of chirps. Bursts obtained with the contact microphone exhibit a much more sustained ringing at a definitely higher frequency than those obtained with the diaphragm microphone. Careful measurements on original photographic records indicate ringing frequencies of 6,000 to 7,000 cycles per second and 3,000 to 3,500 cycles per second for the contact and diaphragm microphones respectively.

Impulse tests are shown in figures 8c and 8d for the contact and diaphragm microphones respectively. The upper traces show the applied force or equivalent sound pressure and the lower traces are the responses obtained. Here the time scale is expanded compared to figures 8a and 8b, 5 milliseconds total in this case, for experimental convenience. Note particularly, however, that the pattern of figure 8a bears a relationship to figure 8b similar to that of figures 8c to 8d. The frequency represented in figure 8c is difficult to interpret from the oscilloscope trace. Frequency response tests on the contact miscrophone show pronounced resonances at 2,000 cycles per second and 4,600 cycles per second, and the harmonic wave analyzer indicates a significant response at only these frequencies on the impulse tests. Under

‖ 1949. Beranek, Leo L. *Acoustic Measurements*, John Wiley & Sons.

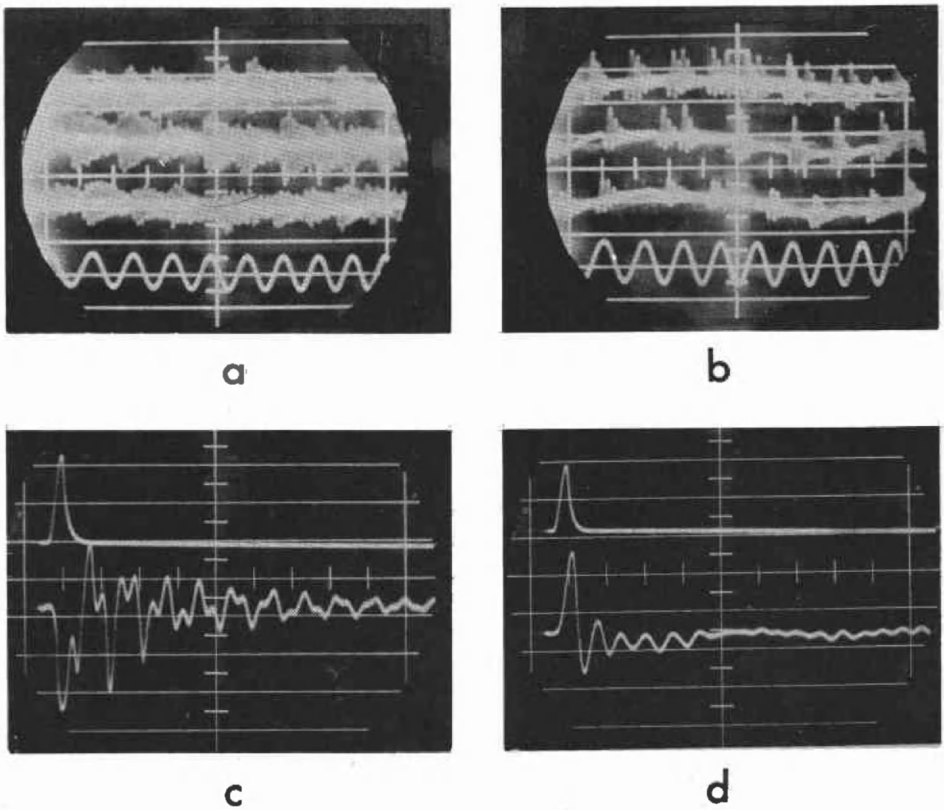


Figure 8. Microphone response: (a) contact microphone response to typical bursts within a chirp, with 500 cps timing wave; (b) same as (a) except diaphragm-type microphone; (c) forcing impulse and contact microphone response, time scale, 0.5 milliseconds per division, 5 milliseconds total; (d) same as (c) except diaphragm-type microphone. Note that the time duration of each sweep in (a) and (b) is approximately 3½ times the duration of (b) and (c).

some conditions, however, the mixing of these two frequencies results in a cathode-ray tube display that may be interpreted as the sum frequency, 6,600 cycles per second. This is believed to account for the appearance of figure 8a. The ringing frequency in figure 8d is clearly defined and checks with the observed resonant peak of 3,300 cycles per second in the diaphragm microphone response.

Obviously the sound wave patterns arising from the chirping of the insect have not been precisely duplicated, nor was it the intent of this phase of the study to do so. However, considering the nature of sound waves and the stimulation effected at frequencies previously mentioned, it appears probable that the true sound waveform is a very highly damped oscillation with a total duration substantially less than the period of the highest frequency (4,600 cycles per second) observed. The waveform of figure 9 is suggested as a possibility.

Despite the uncertainty of the true sound pattern, these tests are believed

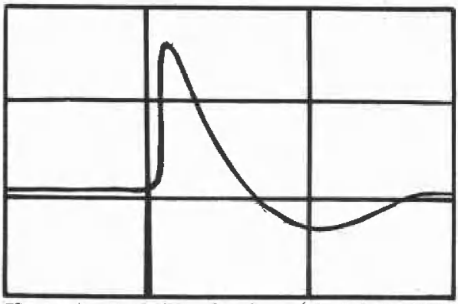


Figure 9. Speculative pattern of single burst within a chirp, not influenced by echoes and resonances.

to show conclusively that the waveforms observed are in error in the fine structure. It further appears that previous observers† §, have ignored vital microphone characteristics in analyzing sound patterns of insects investigated. Correlation between the basic mechanism of stridulation and the sound wave produced is likely to be found primarily in the fine structure of the sound wave. Hence, further study of this problem is deemed highly desirable.

Recommendations

The following recommendations are offered as a result of experience gained on this study:

Equipment

Microphone and amplifier: The combined sensitivity should produce an output of the order of one volt with a peak sound pressure of 40 db above 0.0002 dynes per square centimeter with the electrical noise at the output some 40 db below one volt or approximately 10 millivolts. Typically this might be achieved with a microphone sensitivity of 50 db below one volt per dyne per cm^2 and an amplifier with a gain of 85 db. Frequency and transient response are relatively unimportant if only the gross sound pattern is of interest. But if the fine structure is of interest the frequency limit should be raised as high as possible and the system checked for impulse response to avoid false interpretation of results. Unfortunately, however, the frequency limit for faithful reproduction of the fine structure is as yet unknown.

† See footnote on page 3.
§ See footnote on page 3.

Recorder: Any good commercial tape recorder with a self-noise of 40 to 50 db below one volt at the input should prove satisfactory. Again the frequency response cannot be specified if the fine structure is to be investigated.

Oscilloscope: A laboratory-type oscilloscope of high quality is indispensable for studying details of the chirp, and a camera for recording waveforms is a very useful accessory.

Technique

The low signal levels involved require great care in all electrical circuitry. Complete shielding, grounding, and isolation from supply voltage disturbances are important. Extraneous sounds must be avoided, and vibration isolation must be provided for the specimen under study. The techniques of oscillography are beyond the scope of this paper, and a competent specialist should be consulted for this purpose.

Conclusions

The following are believed to be significant conclusions substantiated by results of this investigation:

Monitoring and recording the chirping or stridulation of subcortical insects can be accomplished with sufficient fidelity to establish the significance of at least some characteristics of the stridulation.

A highly significant "fine structure" exists in the stridulation which has been largely ignored by other investigators and which should be the subject of a concentrated study to determine its full import. This will require a microphone of exceptional sensitivity and damping, and possibly with extended high frequency response. Further efforts in achieving good acoustic coupling to the microphone should be rewarding.

Only a detailed statistical study of all characteristics of the sound pressure patterns can establish the full correlation between the stridulation and the activities of the insect under study.

Acknowledgment

Professors Robert R. Michael and Solon A. Stone, of the Oregon State College Electrical Engineering Department, contributed many hours of their time in analyses of the sound recording needs in this special work. They were able to do this because Professor Louis Stone, Head of the Department of Electrical Engineering, generously authorized the use of laboratory and equipment and staff time.

COVER PHOTO—The wrap-around cover is a reproduction of a photograph of a gallery made by beetles in a Douglas fir tree.

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