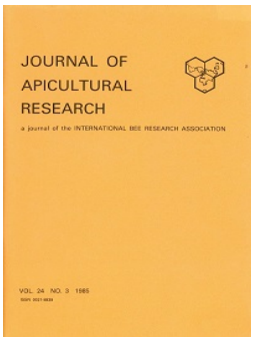

Journal of Apicultural Research

ISSN: 0021-8839 (Print) 2078-6913 (Online) Journal homepage: http://www.tandfonline.com/loi/tjar20

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David G. Dietlein

To cite this article: David G. Dietlein (1985) A Method for Remote Monitoring of Activity of Honeybee Colonies by Sound Analysis, Journal of Apicultural Research, 24:3, 176-183, DOI: 10.1080/00218839.1985.11100668

To link to this article: http://dx.doi.org/10.1080/00218839.1985.11100668

Journal of Apicultural Research 24(3) : 176–183 (1985)

A METHOD FOR REMOTE MONITORING OF ACTIVITY OF HONEYBEE COLONIES BY SOUND ANALYSIS

DAVID G. DIETLEIN*
Department of Environmental Biology, University of Guelph, Guelph, Ontario, Canada N1G 2W1

Revised manuscript received for publication 15 June 1984

Summary

An automated system is described for continuous recording of sound emission by honeybee (*Apis mellifera*) colonies as a measure of activity. Colonies were monitored throughout the year. Output of sound, with respect to both amplitude and duration, was greatest in summer, declined to a low level in autumn, and ceased by December, resuming in mid-January. Colonies from which light was excluded during the winter re-established their normal seasonal pattern at the same time as those exposed to the natural photoperiod. During the active season, diurnal activity was generally high in daytime and low at night; however, initiation of activity did not coincide closely with sunrise nor cessation with sunset. Most of the sound was at frequencies around 300, 410 and 510 Hz.

Introduction

Measurement of cyclic activity in a honeybee colony is of interest in relation to many aspects of behaviour and physiology. For practical beekeeping in temperate regions, the most significant of these is the annual cycle of brood-rearing. After the cessation of brood-rearing in early autumn, honeybees undergo physiological changes (Lotmar, 1939; Maurizio, 1946; Shehata et al., 1981), becoming long-lived 'winter' bees capable of surviving the winter. The nature of the changes that occur at the individual colony levels and the mechanisms by which the changes are linked to the environment are not well understood.

Reports of cyclic activity in honeybees extend back at least to 1898 when Kenyon observed daily fluctuations in weight and seasonal differences in the pattern of daily fluctuation. Beier (1968) noted an endogenous rhythm of 23·5 h in bees kept in continuous light. A circadian rhythm of activity was observed by Spangler (1972*a*) who used a vibration pickup with a small colony in a single-frame observation hive kept in continuous darkness. Daily interruptions of the darkness with 3 h light eliminated the rhythm in the colony but not in individual isolated bees, which became entrained to the light–dark regime. Newly-emerged workers and drones lacked a true circadian rhythm (Spangler, 1972*b*).

In view of the importance of photoperiod in regulating seasonal development in insects (Beck, 1963), one might expect the honeybees' seasonal rhythm to be related somehow to day length. The existence in temperate regions of a seasonal correlation between brood-rearing and photoperiod is certainly apparent. However, a cause–effect relationship, if such exists, has not been established. Changes in the photoperiod after the summer and winter solstices have been suggested as the cues for the seasonal reduction and increase respectively in brood-rearing (Avitabile, 1978; Kefuss & Nye, 1970).

In measuring circadian activity in social insects, the use of whole colonies is desirable because patterns in individuals may not reflect those of the colony. Hebrant (1969), for instance, was unable to distinguish characteristic respiratory rhythms in fragments of a termite colony. Continuous monitoring of honeybee winter-cluster temperature has been used as a measure of activity within the cluster (Corkins, 1932; Gilbert, 1932; Szabo & Pengelly, 1973; Owens, 1971; Southwick & Mugaas, 1971). Background sound level has also been used, though not in continuous recording, in overwintering colonies (Woods, 1959; Wenner, 1962; Eskov, 1970). The sound originates in the cluster from bees rubbing against each other and against parts of the hive structure.

As periodic sampling during an investigation of behaviour may itself interfere with normal behaviour, it is desirable to reduce sampling to a minimum. The present paper describes a procedure for monitoring activity continuously by recording hive background sound. Four devices were constructed and used to record sound patterns throughout the season. Of

*Present address: 26 Broadbent Avenue, Scarborough, Ontario, Canada M1K 4P2

particular interest because of the question of the induction of brood-rearing by honeybees in late winter was a comparison between overwintering colonies exposed to the natural photoperiod and colonies kept in continuous darkness.

Design and Construction

The general principle was as follows: two microphones, one for audio signals from the colony and a second for external noise, were placed between the inner cover and the telescoping outer cover of the hive. The microphones were connected to a differential audio amplifier (Fig. 1) which processed the signals, subtracting the extraneous noise from the honeybee sound signal and amplifying the latter. Noise originated from such sources as wind, aircraft, ground vehicles and voices.

The crystal microphone for the audio signals was mounted inside a pastry cup made of aluminium foil (15-cm diameter), using double-surface adhesive tape, and placed over a screened hole (2·5 cm) drilled in the centre of the lower top cover.

Standard instrumentation amplifiers (IC 741) were used. The amplifier unit can be mounted on protoboard, veroboard or other convenient construction material. Components for the unit are listed in Table 1. All, including the integrated circuits, are readily available and inexpensive. The system diagram for 4 complete differential amplifiers, used for monitoring 4 colonies, is shown in Fig. 2.

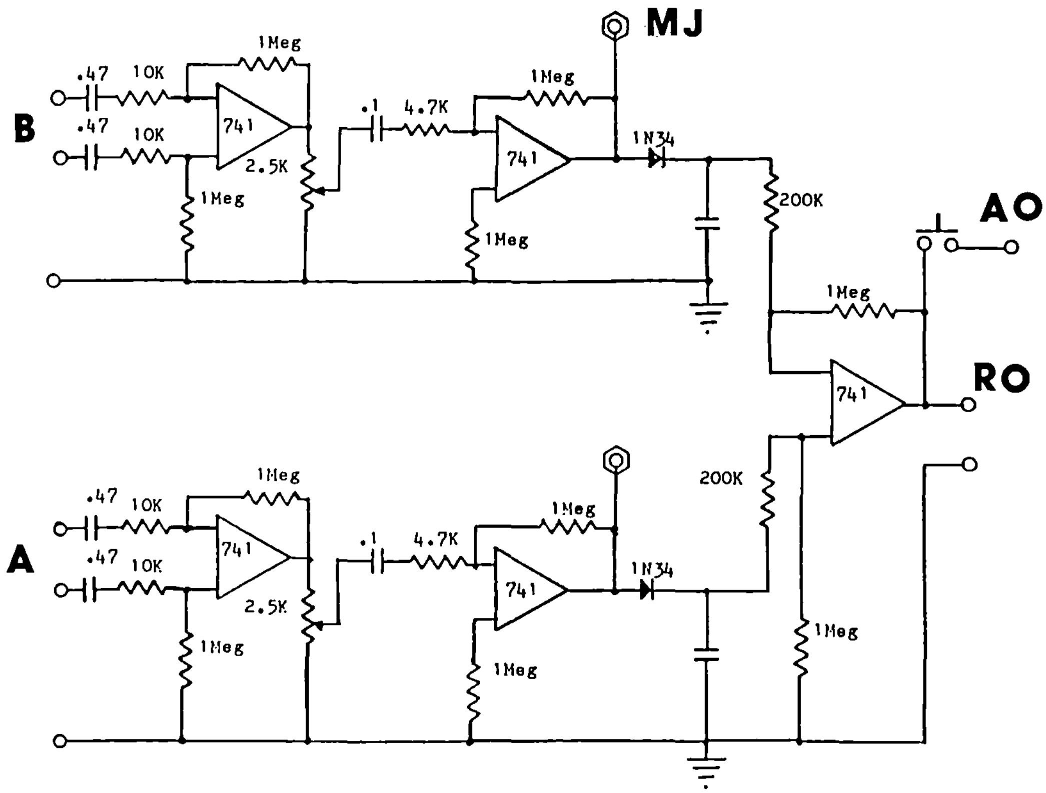

FIG. 1. Circuit diagram of differential audio amplifier used to monitor acoustic emissions from a honeybee colony.
A = extraneous sound; B = bee sound; AO = activity meter output; RO = recorder output; MJ = monitor jack.

TABLE 1. List of amplifier components used in monitoring sound in honeybee hives.

Component	*No. used*	*Description*
IC 741	5	Operational amplifier, dual polarity supply
2.5KΩ	2	Potentiometer, linear
1 MegΩ	10	Resistor 0·25 W
200 KΩ	2	Resistor 0·25 W
10 KΩ	4	Resistor 0·25 W
4·7 KΩ	2	Resistor 0·25 W
0·47 uF	4	Capacitor
0·1 uF	4	Capacitor
1N34	2	Signal diode
SPST	1	Switch
	2	Pin jacks
RS 270-095	2	Crystal microphones

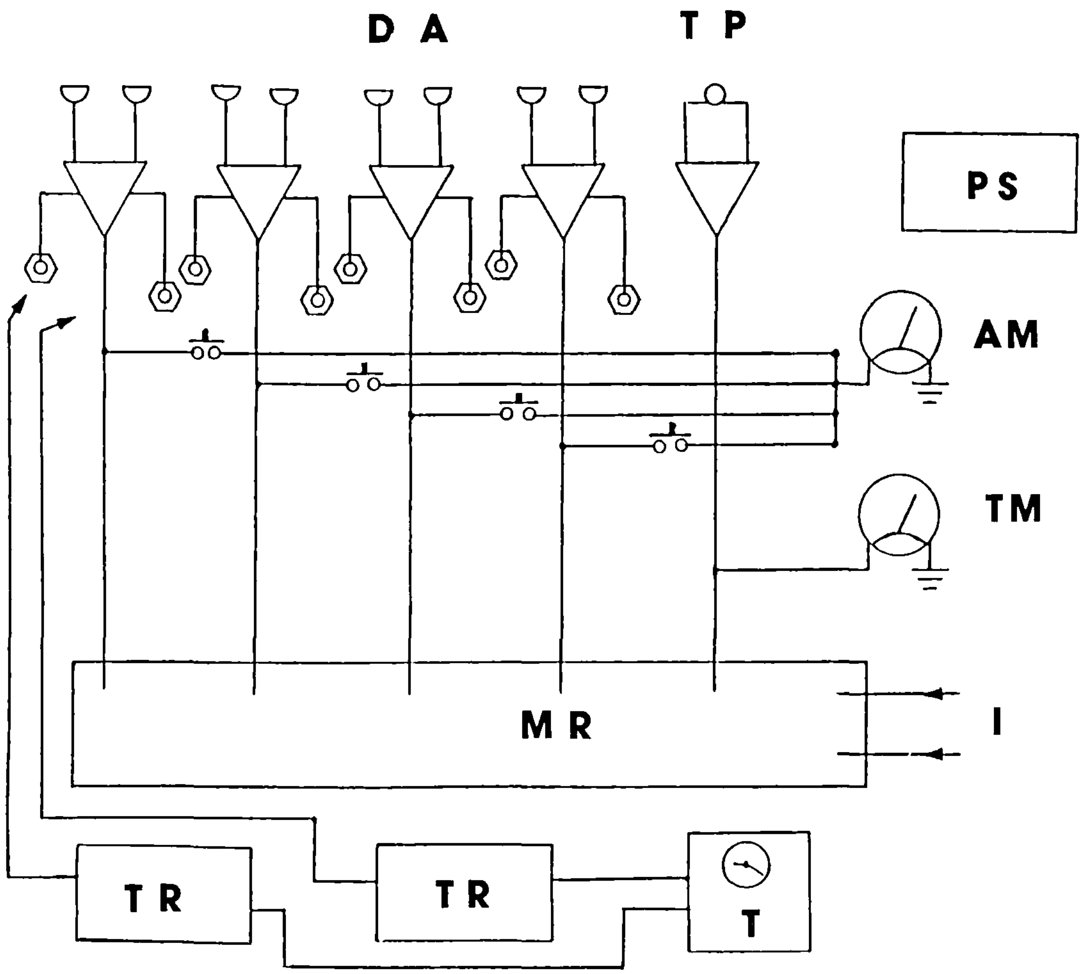

FIG. 2. System of differential sound amplifier used to monitor acoustic emissions from 4 colonies of honeybees. AM = activity meter; TM = temperature meter; MR = multipoint recorder; PS = power supply (+10, -10 V); TP = temperature probe; TR = tape recorder; DA = differential sound amplifier; I = input for hive temperature; T = timer.

Equipment for data collection in winter had to be kept indoors, necessitating the use of long microphone cables. Because of this and other factors, large-diaphragm microphones (RS 270-095) were used. These are highly sensitive and do not require an external power supply, an important consideration when long supply cables are to be used. In the spring, when high sensitivity was not important, an electret-type microphone (RS 270-092A) was used. All crystal microphones were calibrated and tested for output, though not for frequency response. Amplifier response was kept to a roll-off or fall-off of 10 kHz. In the 1979-1980 season the microphones were left exposed, but because their piezoelectric crystals were affected by moisture, all later experiments were performed with the microphones encased in plastic bags. Although this attenuated the signal, it eliminated the need for frequent replacement of microphones.

The audio signal was recorded with a multipoint recorder (Honeywell), specially adapted for the purpose by modifying the recording span to an input range of -10 to $+90$ mV. The negative range on the scale was used to indicate when the extraneous sound (noise) exceeded the audio signal. This occurred very infrequently, except during heavy rainstorms. For simplicity, sound levels were recorded in relative rather than absolute units.

For sound monitoring in the winter of 1980-81, the prototype differential-amplifier system was improved by adding an adjustable gain control.

Spectral frequency analysis

For frequency analysis of the hive-sound spectrum, a 10-filter standard audio analyser was modified to include only bee sound. The filter values used ranged from 50 to 3000 Hz. A detailed description of sound analysis is given by Dietlein (1982). The equations of Berlin (1977) were used to calculate filter values.

Results and Discussion

Seasonal sound patterns

A typical example of the hive background sound level found in a well-managed colony for a 5-day period (26 February–1 March 1980) is shown in Fig. 3. On most days a daily rhythm was apparent, with a rise in amplitude around 8 h and a gradual decrease following the onset of the dark period. A typical daily pattern for a well-managed outdoor colony in spring (Fig. 4, 23 May) was similar, except for a considerably longer interval between sunrise and the increase in sound level. Broad-band level was recorded at hourly intervals throughout the day and night in the spring and summer, a laboratory timer being used to signal the intervals during the night. The broad-band record of total sound level showed a clear daily cycle with a rise-time between 8 and 10 h (Fig. 4). A decrease in the sound level occurred around midnight. Direct observation showed that fanning went on continuously throughout the night, but decreased in the early morning hours. Honeybees were active in foraging throughout the period of the recording except during two very brief rain showers. The summer activity pattern was similar to that of the spring, including a lag of 3–4 h between sunrise and the beginning of increased colony activity. In warm weather, when abundant nectar sources were present, fanning continued late into the night.

Sound records of 3 colonies in the autumn (for 30 September and 1 October) have been included in the same graphs in Fig. 4 to illustrate the similarity in daily rhythms among colonies in this season. In other seasons, individual variation was much greater, each colony having its own rhythm. As autumn progressed, a decrease occurred in the peak amplitude until sound levels were uniform, very weak, and lacking in periodicity. The differential amplifier gain was doubled over that used in the summer in order to show autumn trends clearly. Sound levels tended to decline in amplitude as the season progressed, and the height of the major daily peak also decreased until by December it could no longer be distinguished.

Sound production in overwintering colonies

Four colonies judged to be capable of overwintering successfully were selected for sound monitoring over the winter of 1980–1981. On 1 December hives were placed on stands adjacent to the laboratory and covered with cardboard overwintering covers. Two colonies in hives with unaltered covers were exposed to the natural photoperiod while the remaining two

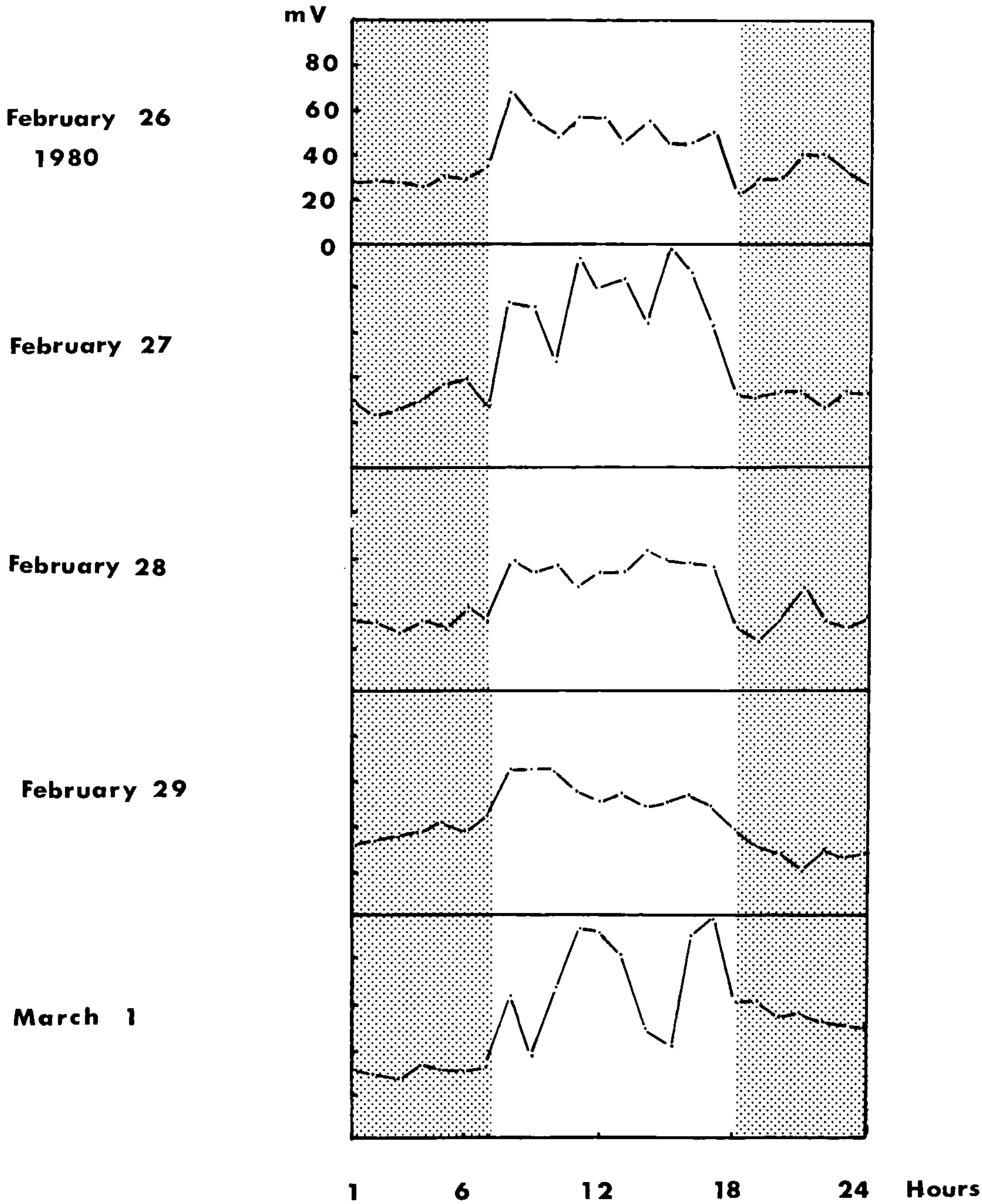

FIG. 3. Typical daily sound rhythms recorded for honeybee colonies in late winter. Stippled areas indicate the natural dark period.

in continuous darkness under overwintering cases, light-proofed with tar-paper. The entrances of the covered colonies were sealed tightly with a layer of tar-paper. Hives were well ventilated by means of roof vents of area *c.* 293 cm^2 (Leigh Canada) with light-baffles made of hive inner-covers.

Six semiconductor temperature probes (Dietlein, 1982) were placed in one control and 6 in one darkened hive, and temperatures were recorded continuously for indications of brood-rearing.

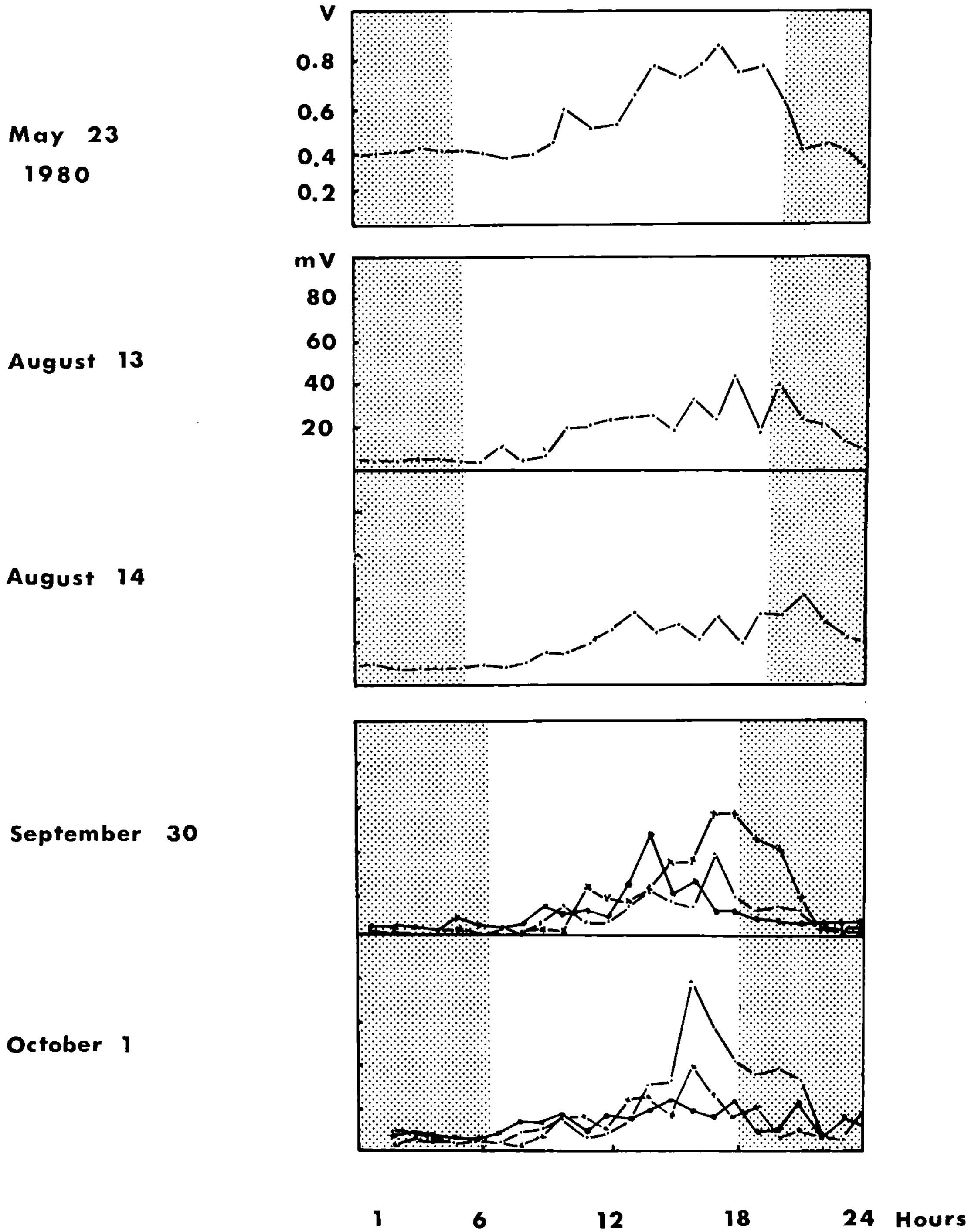

FIG. 4. Typical daily sound rhythms recorded for honeybee colonies in spring, summer and autumn. The voltage scale for May is 10 times the scale for August.

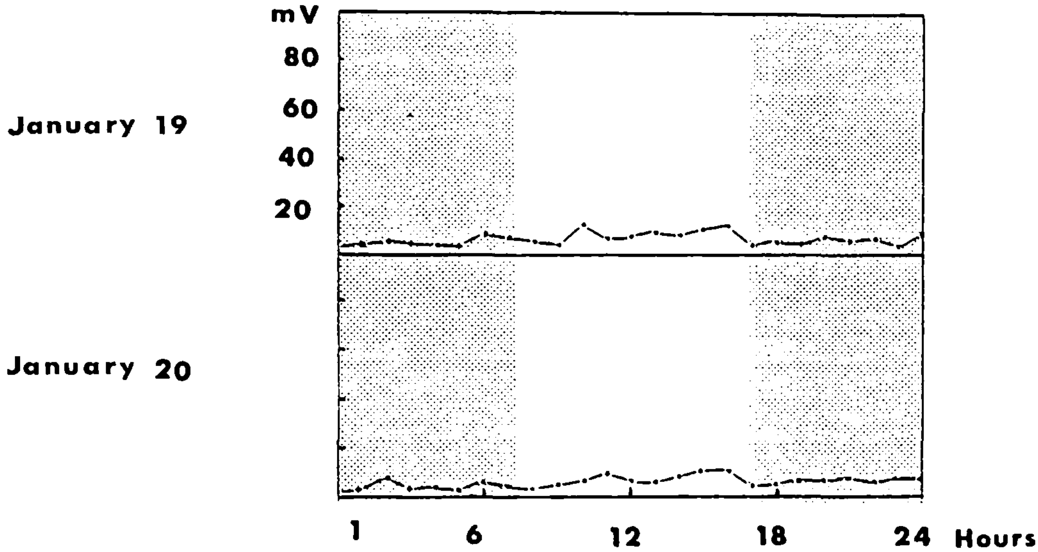

FIG. 5. Typical daily sound rhythms for a honeybee colony in December and mid-January.

Patterns of hive background sound were similar for the colonies in the 2 treatments. In December and mid-January (Fig. 5) there was no regular cycle of activity, then daily small irregular peaks appeared, which by late January or February evolved into a regular cycle with a daily peak in the afternoon. Colonies within a treatment varied with respect to the time when the cycle was established.

By 15 February one temperature probe in each treatment recorded continuous temperatures of 34°C or more, indicating that brood rearing could be taking place (Johansson & Johansson, 1979). By late March or early April continuous high temperatures in several probes suggested that extensive brood-rearing was going on in colonies under the natural photoperiod, but somewhat less rearing in the darkened colonies.

Frequency composition of the hive sound

Most of the hive sound was detected in the 300, 410 and 510 Hz filters of the spectrum analyser, with little sound above 1 kHz. The spectrum varied with season. Spectra in the colonies overwintering under natural photoperiod and in continuous darkness were similar in December and early January but differed in the second week of January, when frequencies below 300 Hz were completely eliminated from the spectrum of the darkened colonies.

Conclusions

The sound-monitoring apparatus described herein worked well for honeybee colonies and could be adapted to other systems.

Although fewer colonies were monitored than one would have wished because of the need to build special equipment, some idea was gained of activity within the hive. On the evidence of sound production, colonies appeared to follow 2 rhythmic patterns of activity, one daily, the other long-term or seasonal. The natural daily rhythm varied with season in both amplitude and duration. Activity was greatest in summer, declined to a very low level in autumn and ceased by December, to resume in late January or early February. This seasonal influence is reminiscent of the seasonal fluctuation in honeybee weights reported by Kenyon (1898).

Although diurnal activity was generally high in the daytime and low at night, initiation and cessation of activity were not closely timed to sunrise and sunset respectively. The general pattern appeared to be subject to considerable modification presumably by such factors as the nectar flow.

The apparent endogenous control of activity in colonies overwintered in darkness underlines the influence of the seasonal rhythm. The timing and nature of the cycle of sound production that developed were correct for the natural photoperiod in late winter (except for irregularities in the frequency spectrum). The resumption of activity in the darkened colonies argues strongly against the lengthening photoperiod in late winter being the signal which induces the population build-up for the new season.

Acknowledgement

I am sincerely thankful for extensive and patient assistance on this project from Dr. R. W. Shuel. Assistance in the apiary was provided by Mr. D. Boyes. I thank my family for their support. Financial support was obtained from the Natural Science and Engineering Research Council, and the Ontario Ministry of Agriculture and Food. The work reported in this paper was part of a thesis submitted to the University of Guelph for the MSc degree.

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