Analysis of coral reef acoustic signatures to assess of ecosystem health of the Phoenix and Line Islands

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Abstract

This abstract needs to be modified.

Mid-ocean coral reefs are often distant from ports where agencies charged with monitoring their health are based. Such distant reefs are difficult to monitor regularly using boats and field crews. However, many reef organisms including fish, mammals, and invertebrates produce unique sounds, which can be monitored remotely as an indicator of reef activity. Additionally, intruding vessels produce other sounds with different characteristics. Recently, acoustic recordings were made at sites in the Phoenix and Line Islands using remote sonobuoys, but the data have not been analyzed. The purpose of this study is to analyze the recorded sounds using sonograms, composite sonograms, and average power spectra to determine the acoustic characteristics of reefs in different states of health. This study will establish a protocol for passive acoustic monitoring of reefs and analysis of the recorded data and determine the feasibility of using passive acoustics to assess reef health.

The use of spectrographic analysis of the acoustic signatures of the sonobuoy recordings revealed that most sounds on the recordings had a dominant frequency of 4000 Hz.

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1 Introduction

Coral reefs provide economic benefits that include tourism dollars and fishery productivity. They are also essential habitats for endangered species such as Hawaiian Monk Seals. Congress has mandated that the health of the US coral reef ecosystems in the Pacific and Atlantic Oceans be routinely monitored for their ecological health so as to protect these resources. The agencies charged with this monitoring include the US Department of Commerce, NOAA, and the National Marine Fisheries Service (NMFS).

However, most of these reefs are scattered across a vast area in the Pacific Ocean from the Line Islands below the equator to the Midway Islands above the equator. In fact, the Hawaiian Island chain alone would reach from Montana to Alabama if superimposed on top of the map of the USA. Monitoring such distant ocean coral reefs can require many resources such as manpower, equipment, vessel time, fuel and post-cruise data analysis. Monitoring these resources thus costs a great deal of time and money, which must be borne by the NMFS. In addition, such surveys are not continuous, but often only visit the remote reef one or perhaps two times a year.

A novel approach to monitor the reefs of the Pacific involves the use of passive acoustics. Many marine animals, including snapping shrimps, sea urchins, drums, parrotfishes, groupers, damselfish, snappers, various cetaceans and other marine mammals make sounds for communication and during feeding behaviors underwater. Using hydrophones positioned at reefs and digital recording media, such biological sounds can be recorded in remote locations and summary statistics, alerts, and raw acoustic data transferred electronically via satellite or phone link to researchers at the base laboratories. These data can be evaluated remotely and monitoring can be done without a large expenditure of time and money. If the situation indicated an unexpected decline in reef acoustic activity, survey crews could be sent out to investigate. In addition, vessel intrusion into marine protected areas can be detected acoustically, as vessels produce characteristic noises while operating in shallow waters. However, to be able to implement such a remote passive acoustics monitoring plan, preliminary baseline data on reef sounds are required. Factors such as weather, sea state, season, day/night photoperiod changes, and migration patterns may cause variations in sound pressure levels and produce unique acoustical signatures.

Recently, four East Carolina University Sonobuoys were deployed on a NOAA research cruise (TC 01-01) between 7 Feb and 23 Feb 2001 at various sites in the Phoenix and Line Islands (Figure 1). Twenty audiocassette recordings were produced at coral reef sites near Howland Island, Baker Island, Jarvis Island, Palmyra Island, and Kingman Atoll, but the data on these recordings have not been analyzed. In this study, we will analyze the acoustic data on the recordings and work with NMFS personnel to correlate the acoustic data with independently collected data on reef health. This study will establish a protocol for using passive acoustic data to as an indicator of coral reef health.

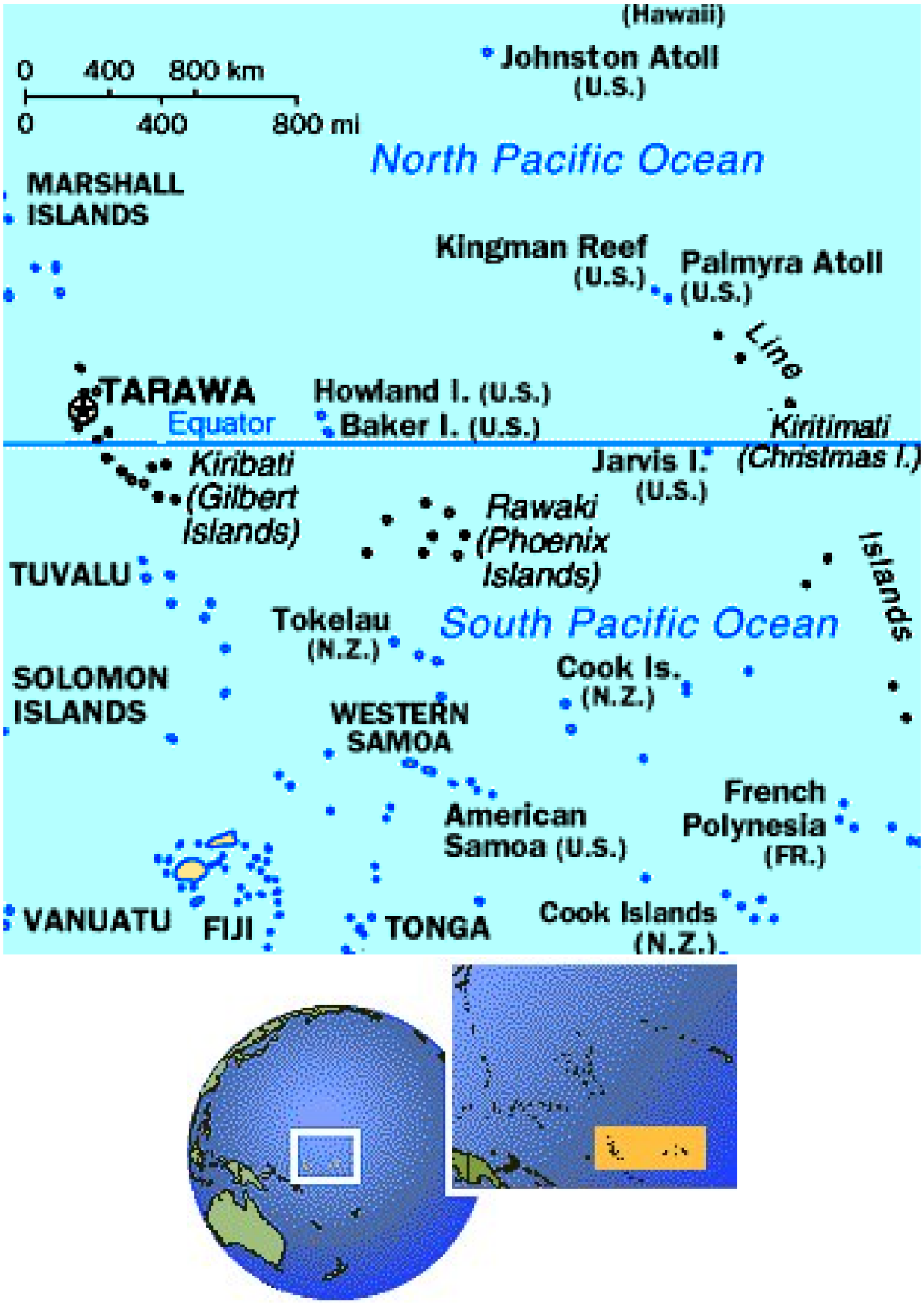


Figure 1: Map of Phoenix and Line Islands

2 Methods

2.1 Data Collection

The use of the passive acoustic monitoring at sites in the Phoenix and Line Islands has been attempted in this preliminary project. We used the ECU sonobuoys to record ambient sounds at each of 20 stations. The sonobuoys were constructed of 30-inch (76.2-cm) sections of 4-inch (10.2cm) schedule 40 PVC plumbing pipe, which acted as a waterproof housing. Externally, there was a hydrophone glued to the tube, and wired to the electronics, which were inside the waterproof PVC housing. Internally, the sonobuoy consisted of a timing circuit, a standard audiocassette tape recorder, and a power supply. A talking clock, set to local time, announced and recorded to tape the time at the start of each sonobuoy recording. The sonobuoys were designed to record for an entire day on one 45-minute cassette tape. This was accomplished by sampling for a relatively short period (one minute thirty seconds) at intervals of 15, 30 or 60 minutes (hereafter called the recording period). In this study, the sonobuoy timers were set to record ambient sounds through the hydrophone at 60-min intervals after a start time (1.5 min x 24 recordings = 36 min of recorded tape). The sonobuoys were typically set to begin recording at 20:00 (8:00 PM) local time and placed at the sampling locations between 14:00 and 16:00 in the afternoon. The following day at the same time the sonobuoys were collected and the tapes removed. The tapes were played to detect any malfunctions and correct them before the next night. An experienced analyst, trained to identify each target species and other soniferous species that occurred in the study area, listened to each sonobuoy tape. There were 20 tapes, one per station per day.

2.2 Sonograms and Power Spectra

Average power spectra in various frequency bands and sonograms were used to analyze the tape-recorded sounds from Howland Island, Baker Island, Jarvis Island, Palmyra Island, and Kingman Atoll. 20 tapes were recorded 7 Feb through 23 Feb 2001 using the ECU Sonobuoy protocol (Luczkovich *et al.* 1999, Luczkovich *et al.* 2000). The acoustic characteristics obtained from these analyses will be compared to an independent assessment of coral reef health so that correlations between acoustic and other data can be developed.

We digitized each tape at a sampling frequency of 24 kHz using a National Instruments Analog to Digital board in a Macintosh computer controlled by Labview software. Overlapping 1024-point power spectra were computed for each recording using a Hanning-windowed FFT. The sample window for each consecutive power spectrum overlapped the previous window by half (512) of the points. A power spectrum separates the sound into its frequency components. A spectrograph (or sonogram) is a plot of power spectra taken in consecutive time slices to show time variation of the frequency components. Power spectra and spectrographs allow researchers to quantify the characteristics of sounds and separate contributions of various sound-producers from the total sound (Sprague *et al.* 2000, Luczkovich *et al.* 2000).

The time convention used in this document is that times on the calendar day following the sonobuoy deployment have an extra 24 hours added to them. For example, 32:30 represents the time 08:30

on the day after deployment. $(32 = 8 + 24)$

The composite sonograms are three-dimensional plots with time on the x-axis, frequency on the y-axis, and sound energy (called power spectral density) on the color–or grayscale–axis. Each vertical slice of a composite sonogram is an average power spectrum from an entire hourly sonobuoy recording (beginning after the beep and time announcement). The sonograms in this report are on a 30-dB scale. Completely white represents the background, a voltage of 1.00 mV on the recording playback (or a time at which the power spectrum was not computed), and completely black represents 30 dB above the background level, 31.6 mV on the recording playback. The composite sonograms represent the changes in the average power spectrum throughout the day. These plots are best at representing long-duration or repetitive sounds. Single, short-duration sounds will not appear in average sonograms because they would be averaged with long periods of no sound.

2.3 Snapping Shrimp Level (SSL)

Since snapping shrimp are abundant the acoustic recordings, we computed a sum of the sound energy in the frequency band 2000–7000 Hz in which snapping shrimp sounds dominate over other sounds such as wave noise. We call this spectral band sum the snapping shrimp level (SSL). We computed the SSL by summing the power spectral densities for frequencies between 2000 and 7000 Hz in power spectrum (excluding the beep and time announcement) during an hourly sonobuoy recording. An SSL vs. time graph, a 24 h average SSL, and the night-day ratio of SSL are useful. The 24 h average SSL is an average of the SSL for 24 consecutive hourly sonobuoy recordings. The night-day ratio of SSL is the average SSL for night recordings, taken as 22:00–31:00 (or 07:00 on the next day), divided by the average SSL for day recordings, taken as deployment time (usually 13:00–17:00) until 18:00 and 33:00 (09:00 the next morning) until 24 h past the deployment time. The ratio of night to day SSL normalizes variations dus to hydrophone or recorder sensitivity as well as those due to distance to the snapping shrimp aggregation.

3 Results

We digitized each tape at a sampling frequency of 24 kHz using a National Instruments Analog to Digital board in a Macintosh computer controlled by Labview software. Overlapping 1024-point power spectra were computed for each recording using a Hanning-windowed fast Fourier transform (FFT). The sample window for each consecutive power spectrum overlapped the previous window by half (512) of the points. We used the power spectrum output to compute the composite sonograms and the SSL data. Table 1 contains a summary of the location data as well as the SSL data for each tape. Composite sonograms and SSL plots for each tape are given in the Appendix in Figures 2–31.

Tape	Location	Depth	Sonobuoy	Average SSL	Night/Day Ratio
01	Howland Is (SW reef wall)	15 m	7	-20.7 dB (24 h)	3.1 dB
02	Howland Is (NW reef wall)	15 m	6	N/A	N/A
03	Howland Is (SE reef slope, exposed)	14 m	1	-20.9 dB (22 h)	1.3 dB
04	Howland Is (E reef slope, exposed)	9 m	5	-25.6 dB (21 h)	1.6 dB
05	Baker Is (SW corner wall)	15 m	5	-24.8 dB (24 h)	3.4 dB
06	Baker Is (W wall)	16 m	7	-19.8 dB (24 h)	3.0 dB
07	N/A	N/A	N/A	N/A	
08	Baker Is (E terrace)	10 m	1	-23.0 dB (22 h)	1.0 dB
09	Jarvis Is (SW X S reef terrace)	8 m	5	-21.8 dB (24 h)	1.5 dB
10	Jarvis Is (SW x W reef shelf break)	9 m	1	-25.9 dB (24 h)	1.8 dB
11	N/A	N/A	N/A	N/A	
12	Jarvis Island (S)	?	6	-18.6 dB (24 h)	0.9 dB
13	Palmyra Island (S reef slope)	14 m	5	-30.3 dB (24 h)	4.3 dB
14	N/A	N/A	N/A	N/A	
15	N/A	N/A	N/A	N/A	
16	Palmyra Island (SE reef slope)	6 m	16	-20.0 dB (23 h)	0.9 dB
17	Kingman Atoll (Outer La Paloma Pass)	8 m	5	-29.8 dB (24 h)	0.0 dB
18	Kingman Atoll(E lagoon patch reef)	5 m	?	N/A	N/A
19	Kingman Atoll (E pools, lagoon)	5 m	7	-27.7 dB (24 h)	4.3 dB
20	?	?	?	-24.0 dB (24 h)	3.6 dB

Table 1: Summary of results from tape analysis. A value of N/A indicates that the data are not available due to sonobuoy malfunction. A value of ? indicates that the data are missing.

4 Discussion

It is difficult to compare absolute quantities such as sound level or SSL between sites due to differences in ambient noise due to waves and other noise sources. The SSL eliminates much of the noise because it only uses the frequencies in which snapping shrimp dominate. The maximum average SSL (see Table 1) of -18.6 dB was measured on Tape 12, recorded on the south side of Jarvis Island. The minimum average SSL of -30.5 dB was measured on Tape 13 recorded on the south reef slope of Palmyra Island. Does this mean that there was more snapping shrimp activity at the Jarvis Island site than the Palmyra Island site? Possibly, but not necessarily. The problem is that each sonobuoy deployment location has unique sound propagation properties. Also, each sonobuoy could have been a different distance to the sound sources. Sound level decreases with distance from the source.

To account for locational variations as well as variations in individual sonobuoy response, we computed the ratio of night and day SSL-values. The justification is that bioacoustic activity often increases at night and decreases in the daytime. Since the numerator and denominator of the ratio both depend on the same sonobuoy response characteristics and locational parameters, these quantities cancel out. Maximum night-day ratios of 4.3 dB were measured on Tape 13 recorded on the south reef slope of Palmyra Island and on Tape 19 recorded in the east pools of the lagoon at Kingman Atoll. The minimum night-day ratio was measured on Tape 17 recorded at the Outer La Paloma Pass at Kingman Atoll. The biological significance of the night-day ratio in the coral reef environment is unknown because this parameter has never been compared with direct observations.

5 Conclusion

Here is a conclusion.

References

Luczkovich. J. J., M. W. Sprague, S. E. Johnson, and R. C. Pullinger. (1999). Delimiting spawning areas of weakfish *Cynoscion regalis* (Familiy Sciaenidae) in Pamlico Sound, North Carolina using passive hydroacoustic surveys. *Bioacoustics*, **10**, 143-160.

Luczkovich, J. J., H. J. Daniel III, M. Hutchinson, T. Jenkins, S. E. Johnson, R. C. Pullinger and M. W. Sprague. (2000). Sounds of sex and death in the sea: bottlenose dolphin whistles suppress mating choruses of silver perch. *Bioacoustics*, **10**, 323-334.

Sprague, M. W., J. J. Luczkovich, R. C. Pullinger, S. E. Johnson, T. Jenkins, and H. J. Daniel, III. (2000). Using spectral analysis to identify drumming sounds of some North Carolina fishes in the family Sciaenidae. *J. Elisha Mitchell Soc.* **116**(2), 124-145.

Appendix

The following pages contain composite sonograms and SSL plots for each tape that recorded data.

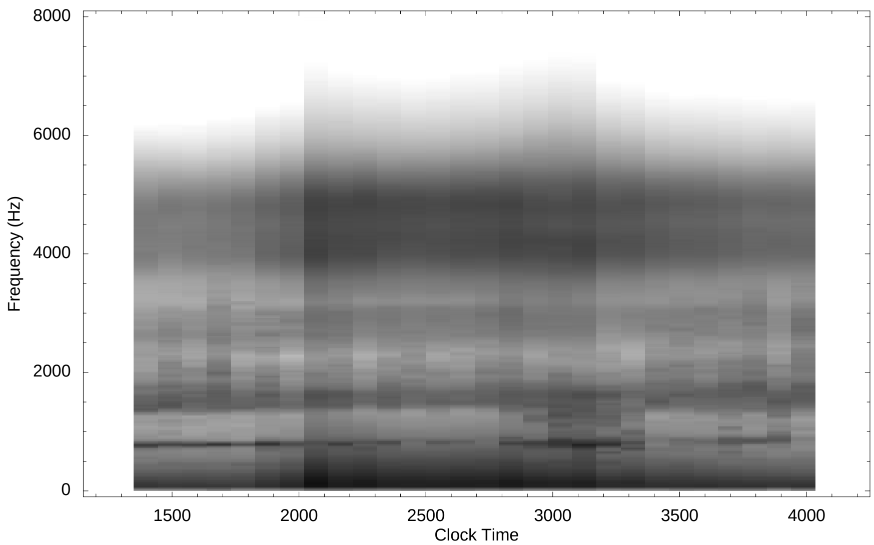


Figure 2: Composite sonogram for Tape 01

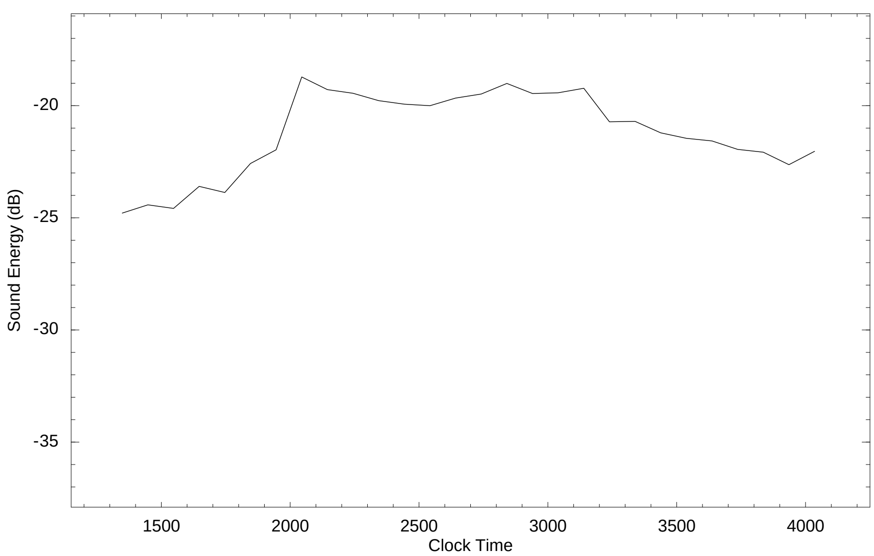


Figure 3: SSL for Tape 01

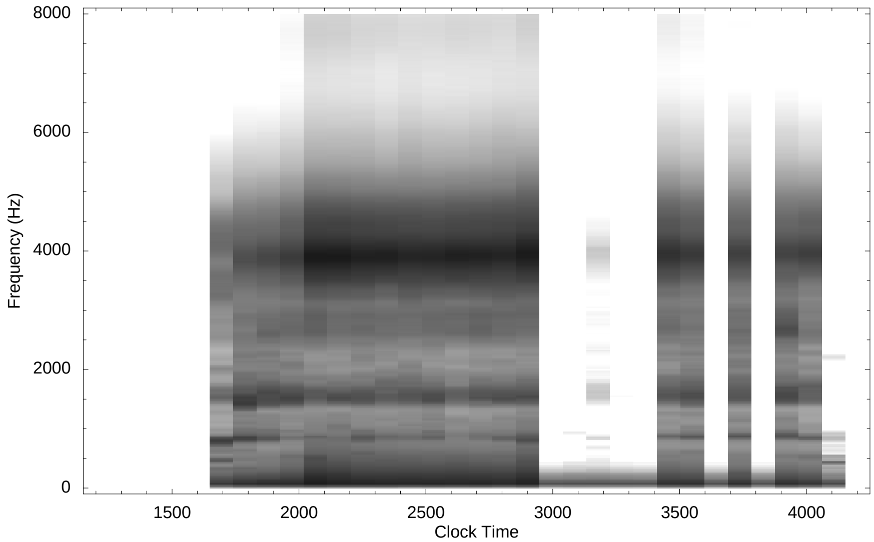


Figure 4: Composite sonogram for Tape 02. **Note:** The sonobuoy malfunctioned when recording Tape 02 causing the average SSL and the Night/Day ratio to be inaccurate.

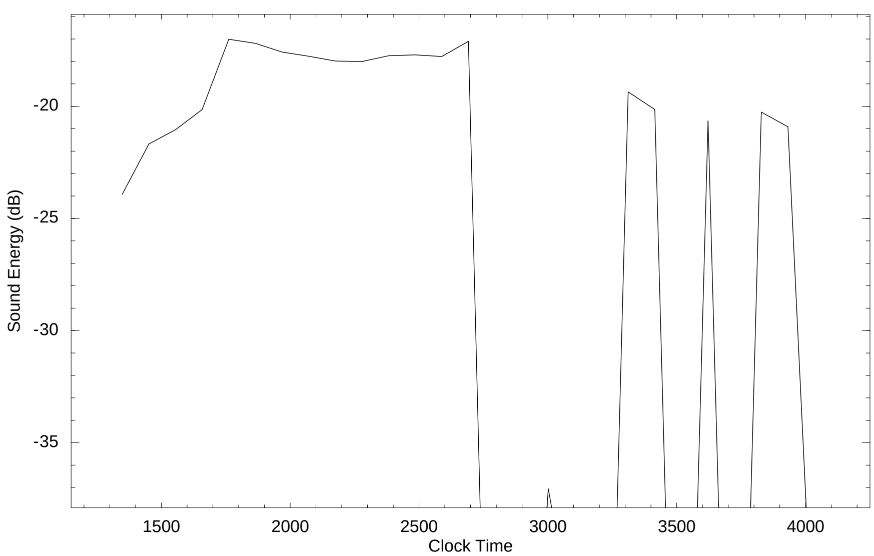


Figure 5: SSL for Tape 02. **Note:** The sonobuoy malfunctioned when recording Tape 02 causing the average SSL and the Night/Day ratio to be inaccurate.

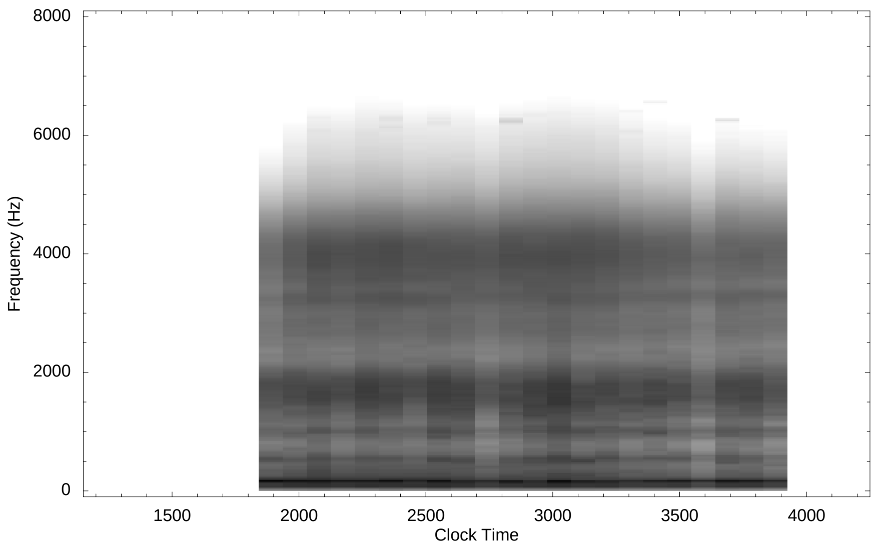


Figure 6: Composite sonogram for Tape 03

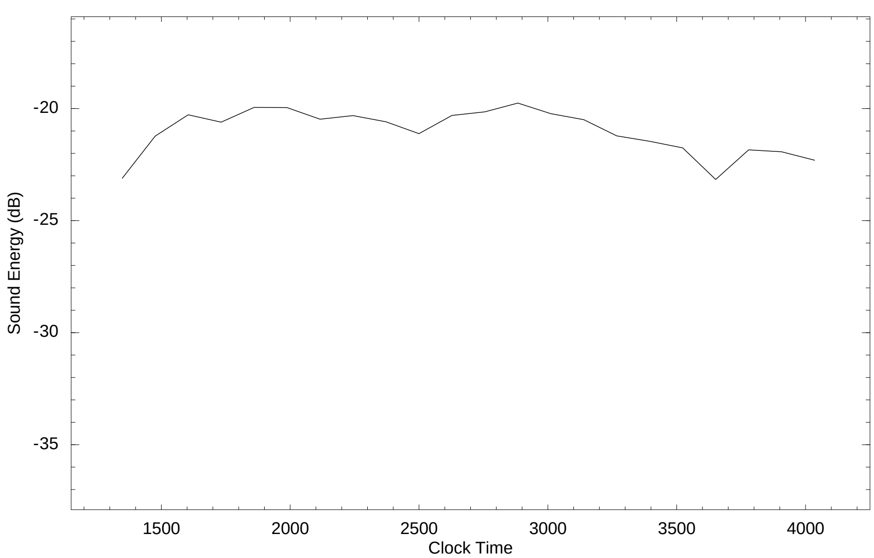


Figure 7: SSL for Tape 03

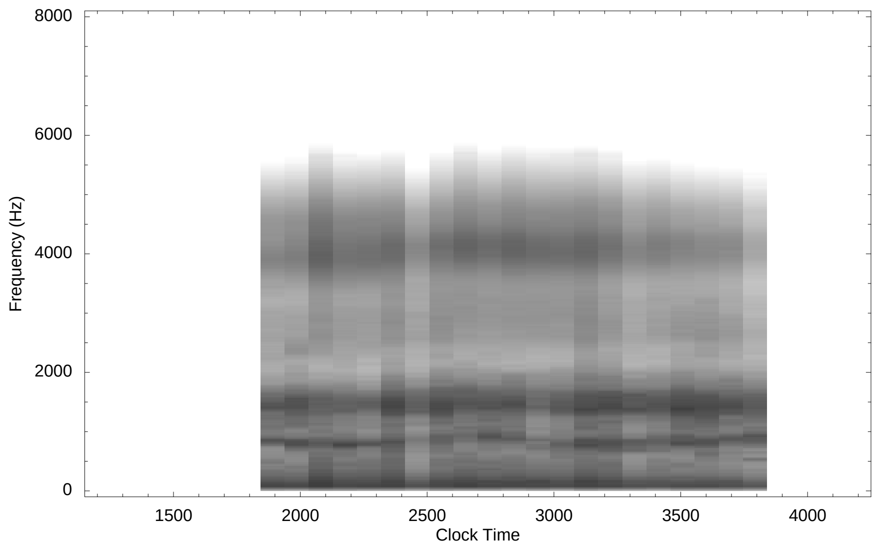


Figure 8: Composite sonogram for Tape 04

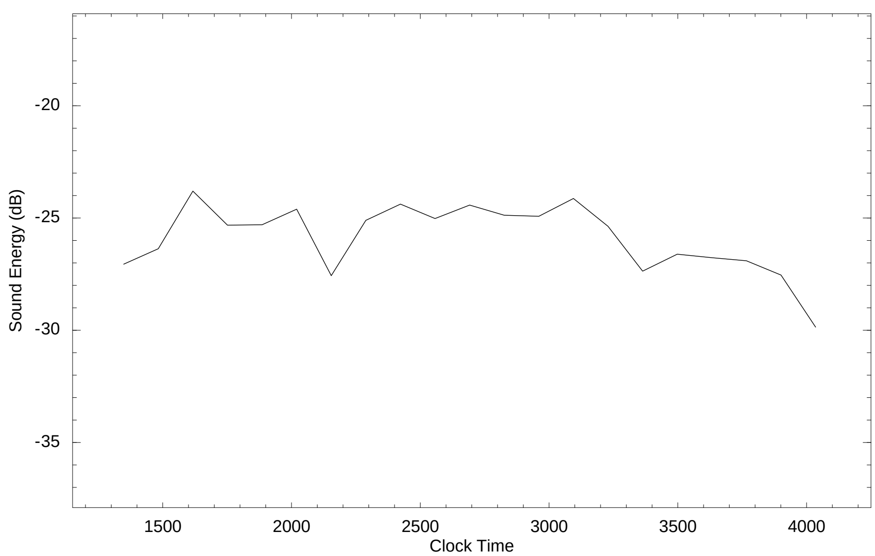


Figure 9: SSL for Tape 04

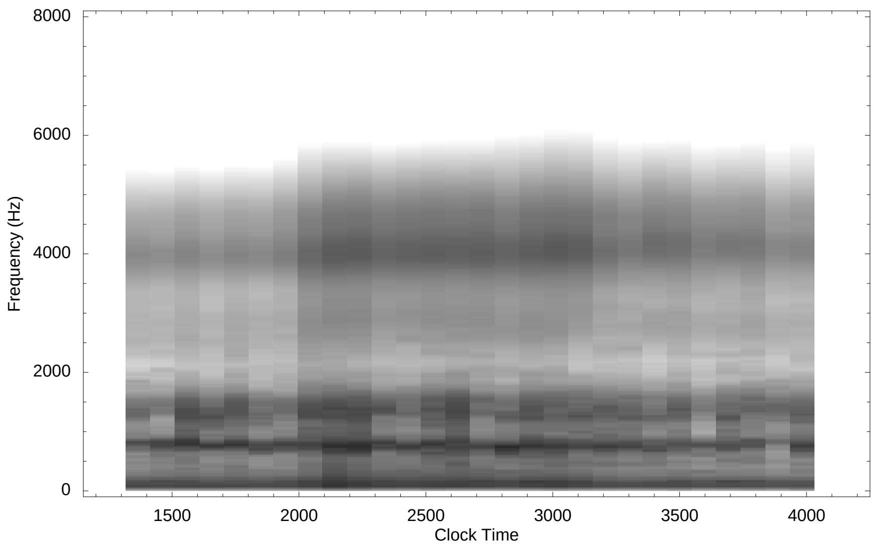


Figure 10: Composite sonogram for Tape 05

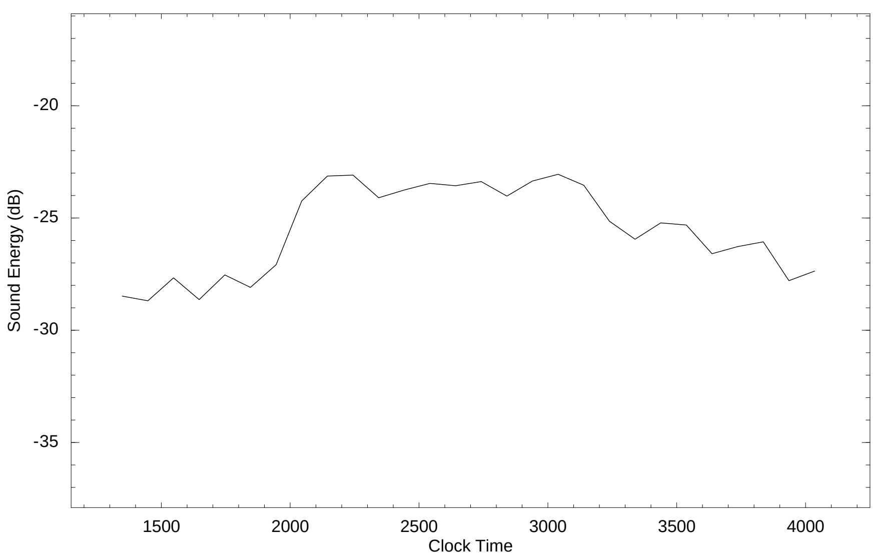


Figure 11: SSL for Tape 05

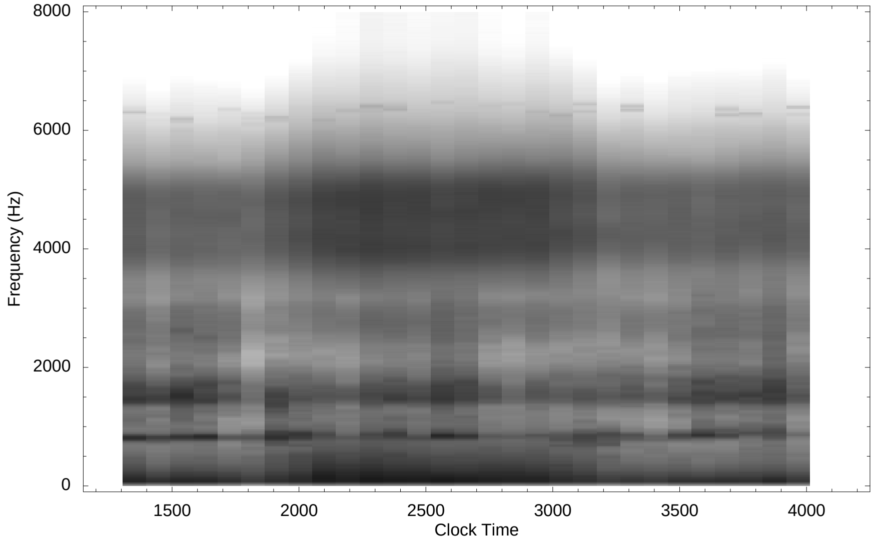


Figure 12: Composite sonogram for Tape 06

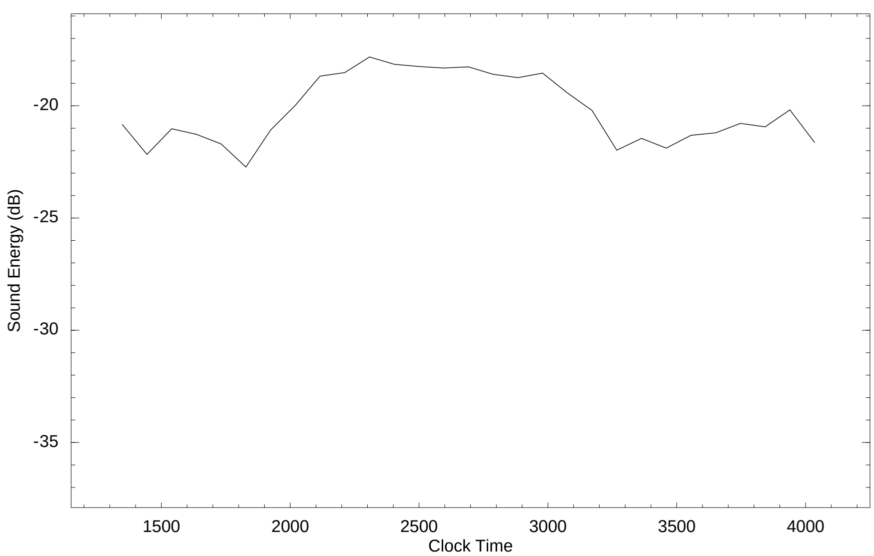


Figure 13: SSL for Tape 06

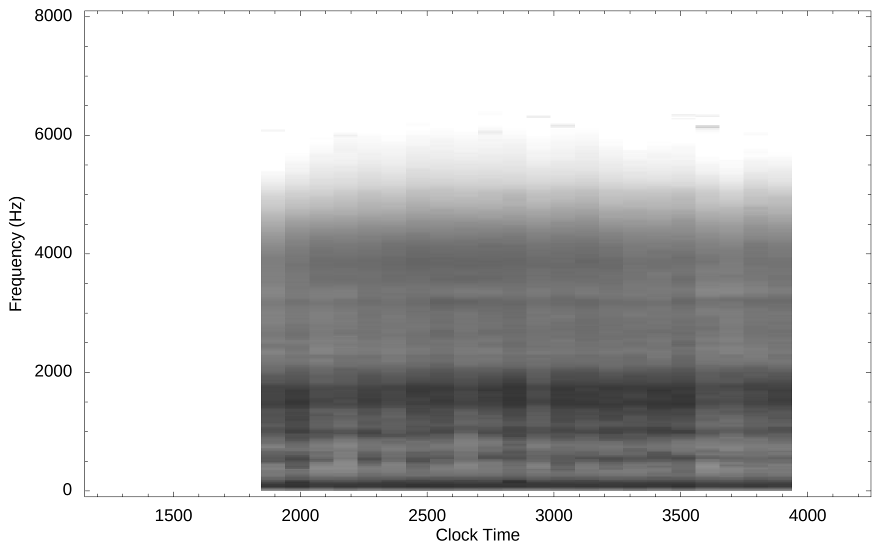
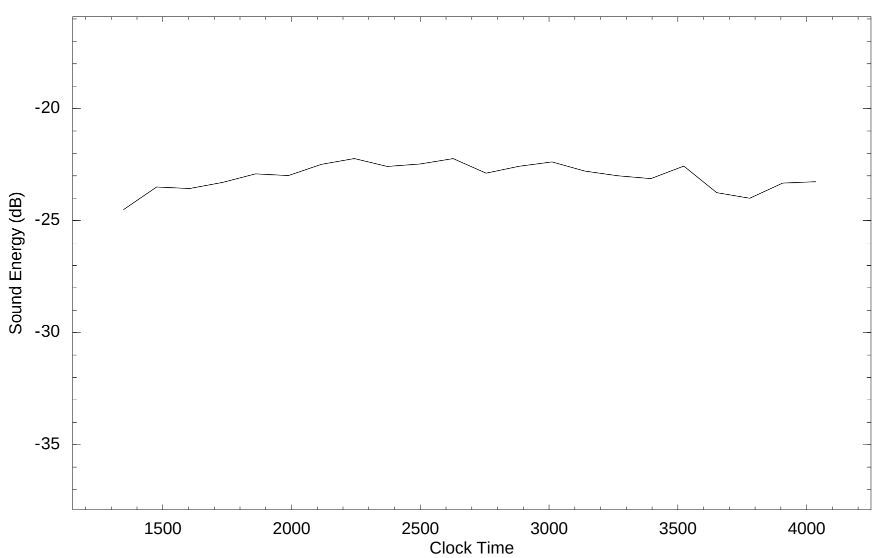


Figure 14: Composite sonogram for Tape 08



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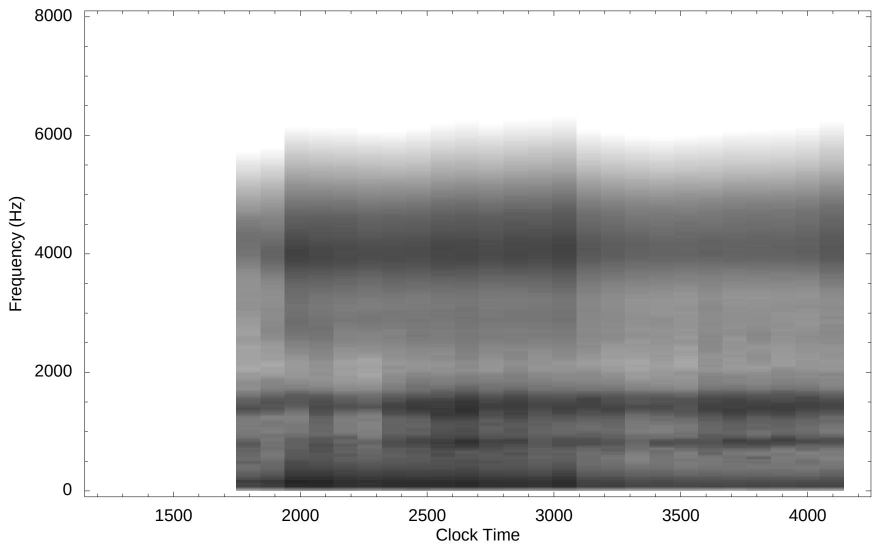
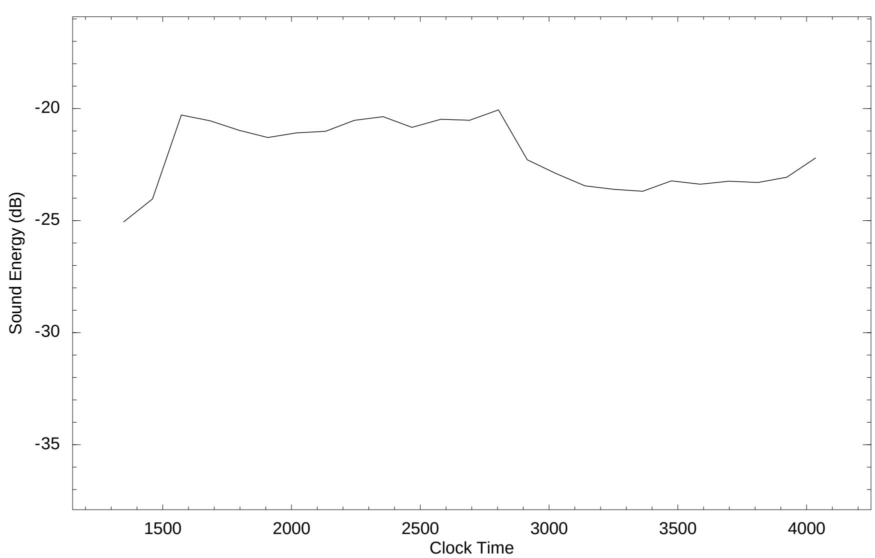


Figure 16: Composite sonogram for Tape 09



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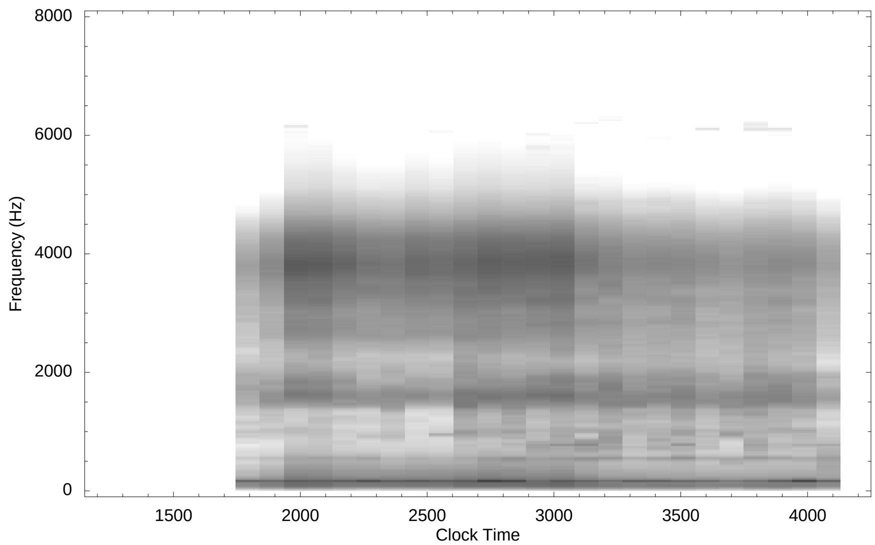
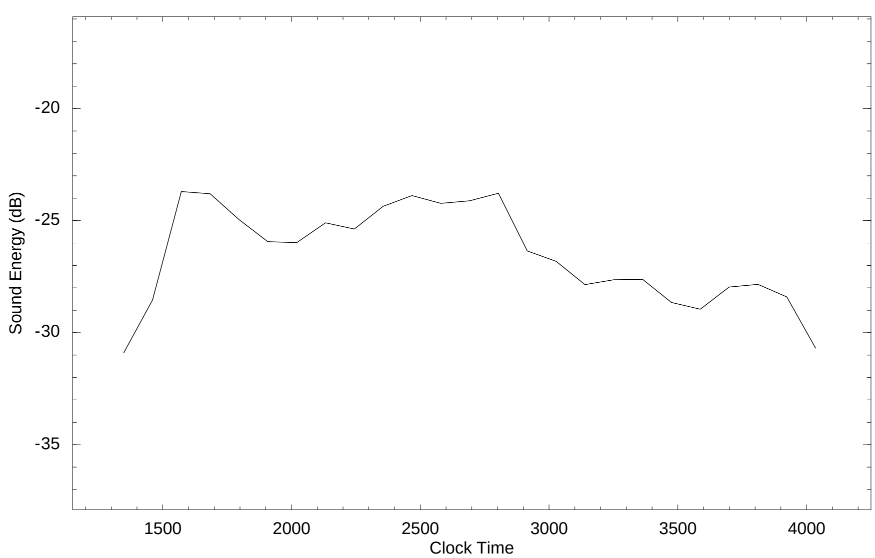


Figure 18: Composite sonogram for Tape 10



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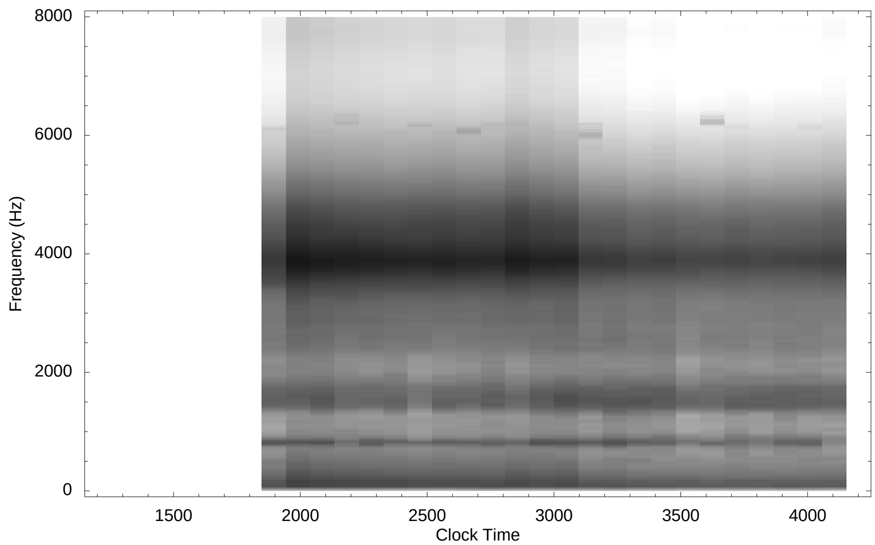


Figure 20: Composite sonogram for Tape 12

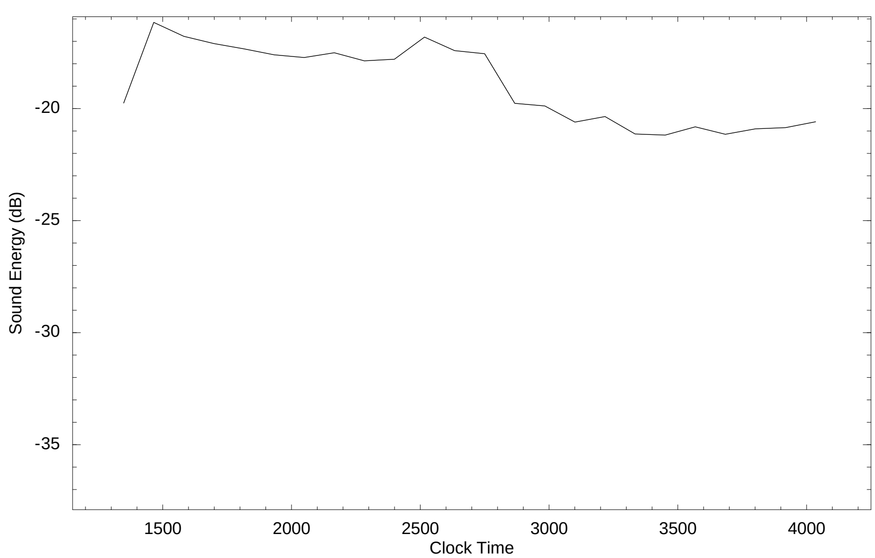


Figure 21: SSL for Tape 12

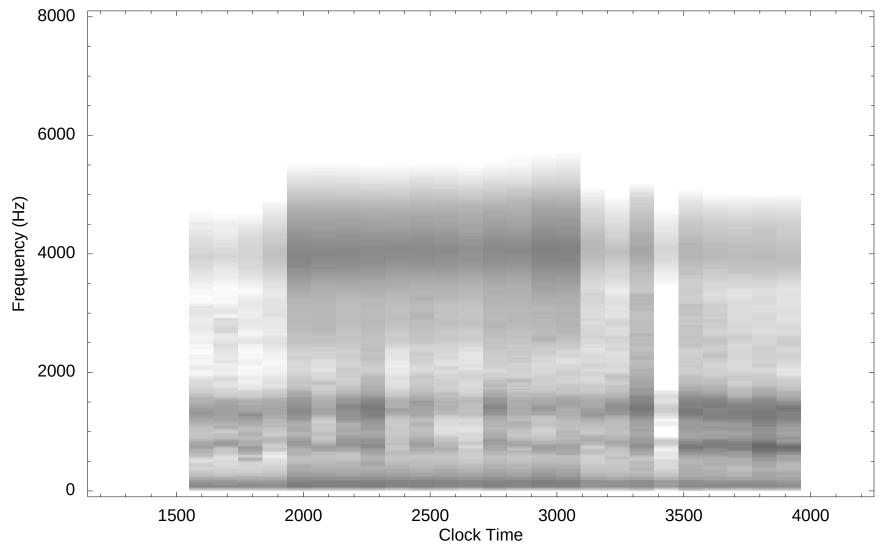


Figure 22: Composite sonogram for Tape 13

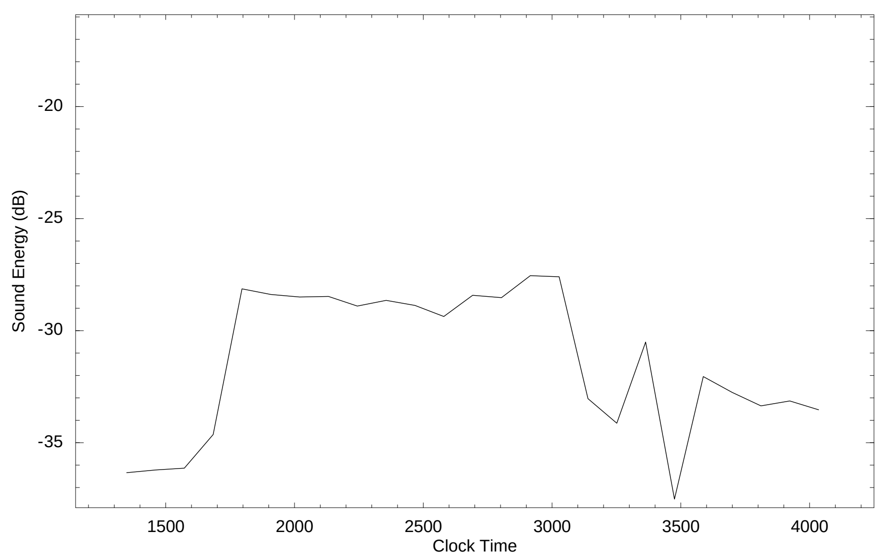


Figure 23: SSL for Tape 13

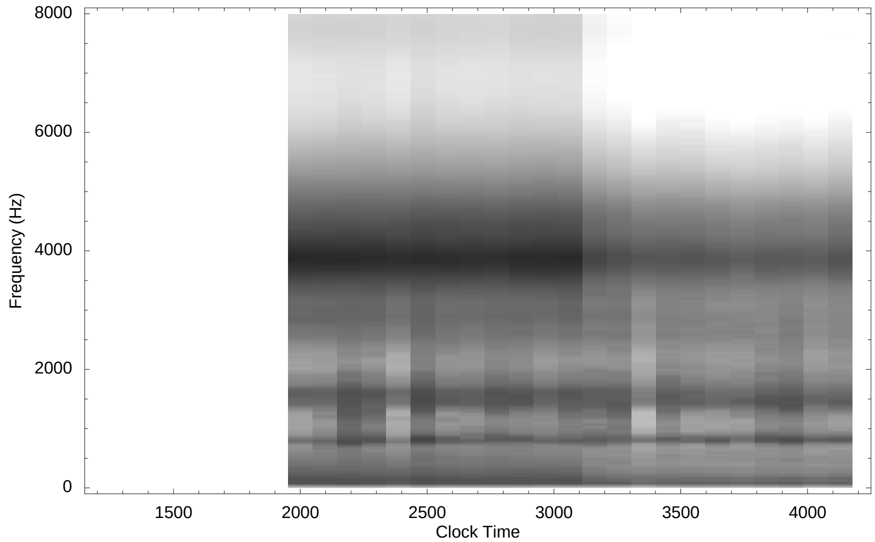


Figure 24: Composite sonogram for Tape 16

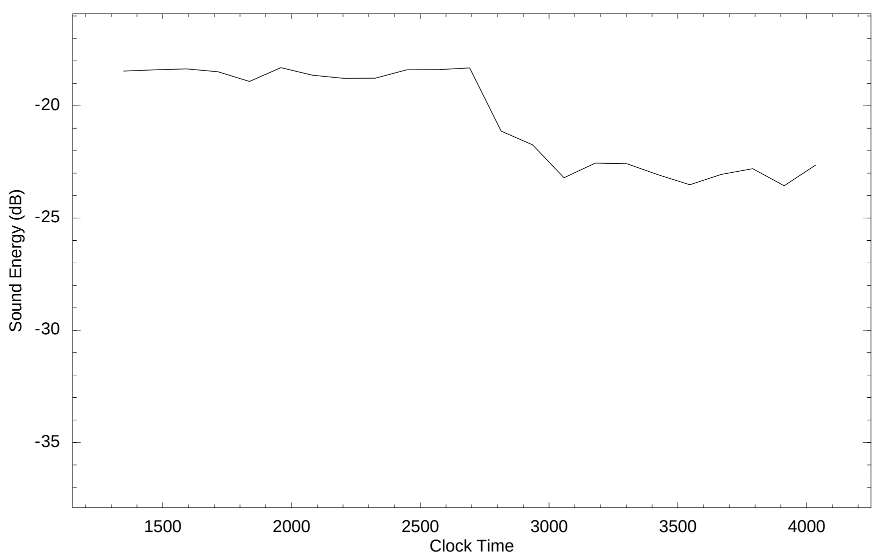


Figure 25: SSL for Tape 16

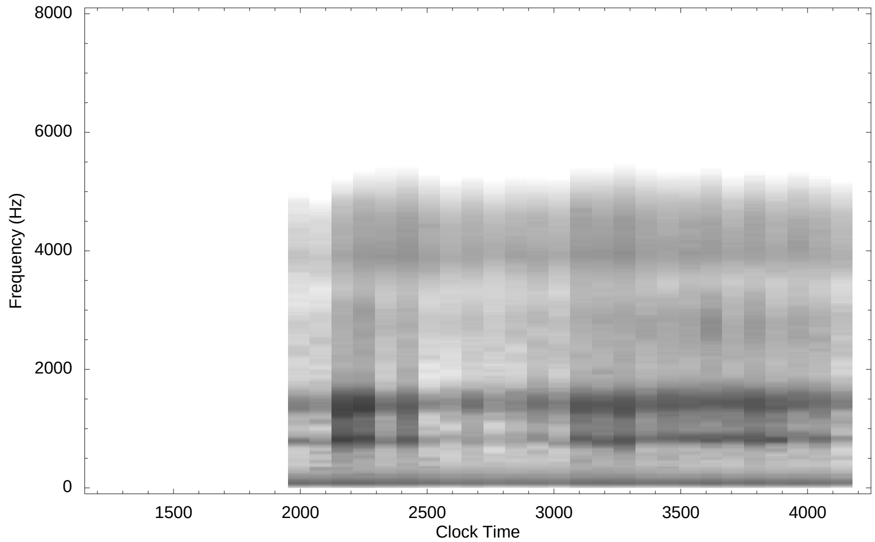
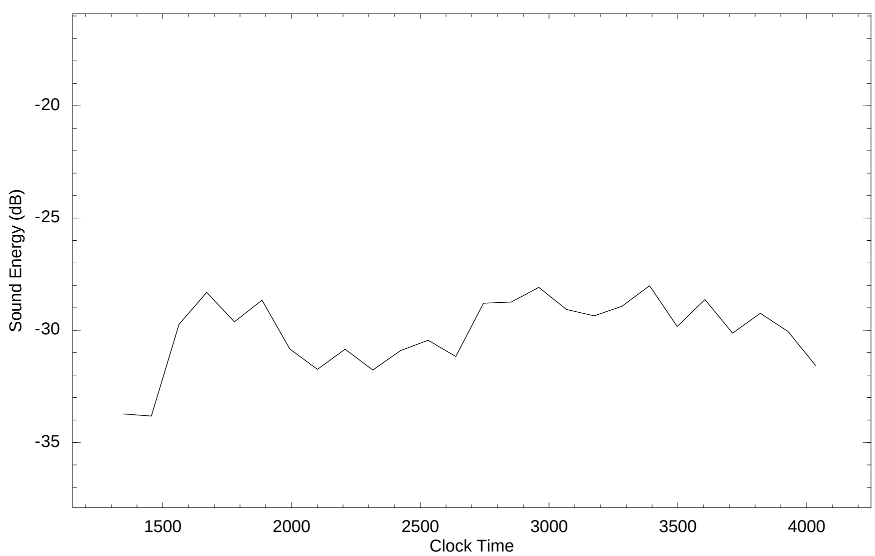


Figure 26: Composite sonogram for Tape 17



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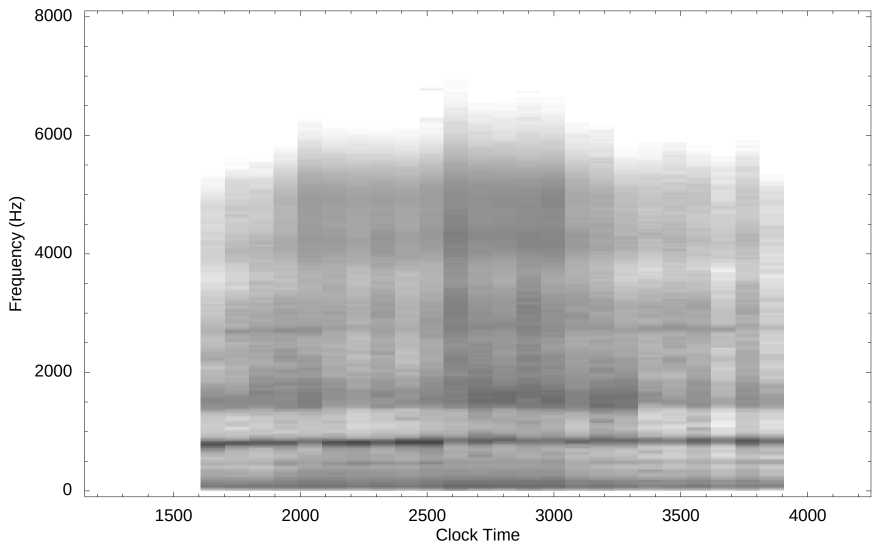
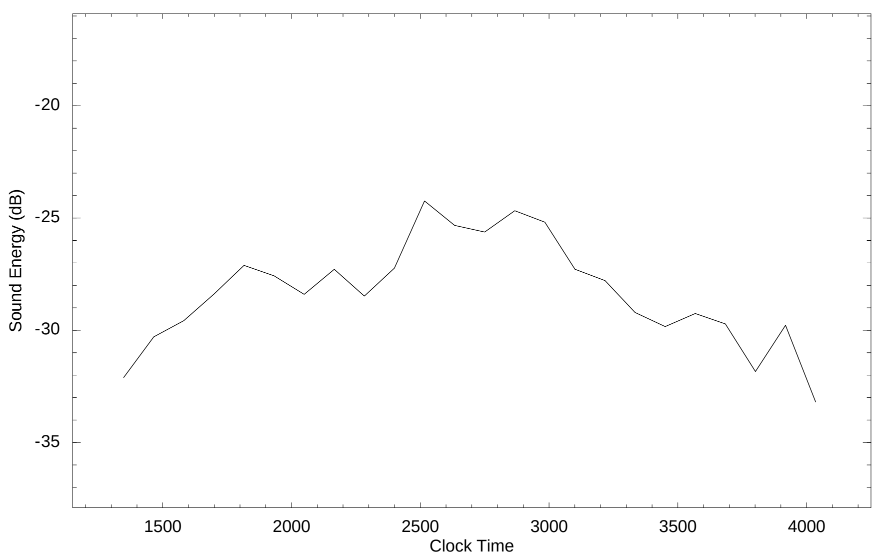


Figure 28: Composite sonogram for Tape 19



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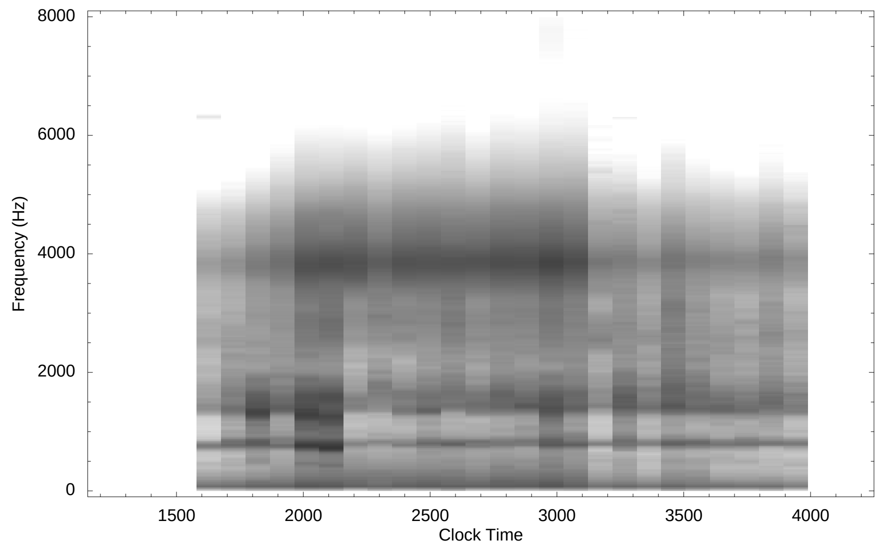

Figure 30: Composite sonogram for Tape 20

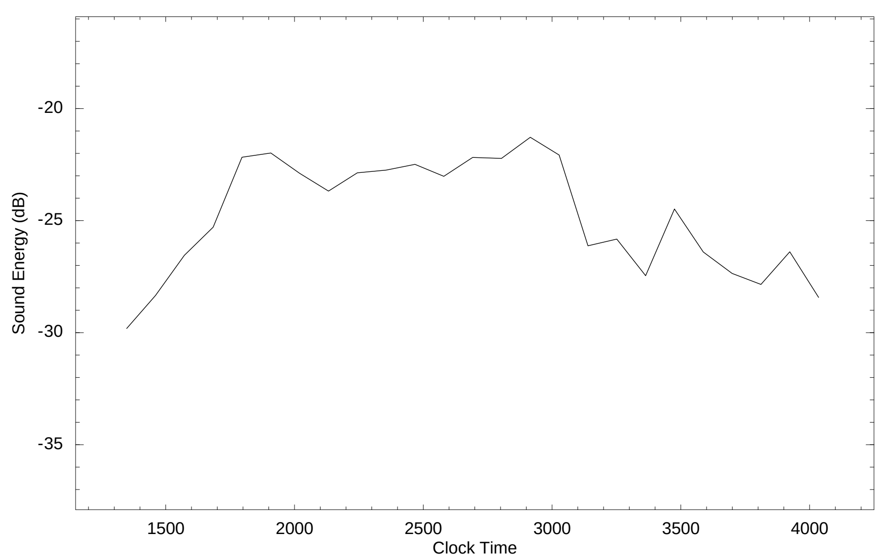

Figure 31: SSL for Tape 20