Report for the Conjoined Public Inquiry Concerning:

WIN 370-4 Craiginmoddie Wind Farm, Dailly, South Ayrshire, KA26

WIN 370-5 Carrick Wind Farm, South of Straiton, South Ayrshire, KA19

WIN 370-6 Knockcronal Wind Farm, Knockcronal, Straiton, South Ayrshire, KA19

Document IARO23-C2

April 2023

International Acoustics Research Organization

IARO Is an international group of researchers with a mission to investigate acoustical environments, especially with respect to features that affect humans and animals, and to publish the results. IARO holds the ethics approval for the CSI-ACHE, the Citizen Science Initiative into Acoustical Characterisation of Human Environments, the results of which are publicly disseminated.

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Acronyms and Symbols Used in this Report

BPF	Blade-pass Frequency
CSI-ACHE	Citizen Science Initiative for the Acoustical Characterization of Human Environments
P_{tot}	Total Harmonic Prominence
P_{peak}	Peak Harmonic Prominence
IWT	Industrial Wind Turbine
P_{harm}	Peak Harmonic Prominence limited to below 5 Hz
SPL	Sound Pressure Level
WPP	Wind Power Plant
WTAS	Wind Turbine Acoustic Signature

A. SUMMARY

1. Craiginmoddie, Carrick and Knockcronal Wind Power Plants (WPPs) are currently being proposed for South Ayrshire.

2. High-resolution recordings of low-frequency sound and infrasound were obtained at several locations near these proposed WPPs.

3. The purpose of these recordings was to document the baseline soundscape prior to, and in anticipation of, a formal consent for these proposed WPPs.

4. The presence or absence of existing Wind Turbine Acoustic Signatures (WTAS) was determined for each of the locations and their likely sources are indicated.

5. The following locations are already subjected to WTAS from several other, WPPs: Knockskae Cottage, Glenalla Farm, Little Garroch, Glengennet, Tairlaw House, Glenhead, and Barnfield.

6. A further WTAS source, with a BPF at or above 1 Hz, affected Knockskae Cottage, Glenalla Farm, Little Garroch, Glengennet, Glenhead and Barnfield. Its source could not be identified.

7. All locations affected by this unknown source were also affected by a 20-hertz tone, also of unknown origin.

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B. INTRODUCTION

I. Goal

8. Acoustical monitoring of the baseline soundscape in vicinity of the proposed Craiginmoddie, Carrick and Knockcronal WPPs in anticipation that consent may be granted.

II. Disclaimer

a. The authors of this report are not party to anti-technology sentiments.

b. Wind turbines are considered by the authors as welcome additions to modern technological societies.

c. In no way can or should this scientific report be construed as a document arguing for or against the implementation of wind power plants, or any other type of industrial complexes.

d. The authors of this report (Crosthwaite & Grosvenor) have been paid for direct costs incurred and/or nominal hourly rates for obtaining recordings.

e. IARO has been paid for analyses and production of this report at a nominal hourly rate. This money is used entirely for costs associated with open-access publication.

f. The IARO authors (Alves Pereira & Bakker) received no financial benefit from analyses and the production of this report.

III. International Acoustics Research Organization, IARO

9. The International Acoustics Research Organization represents a group of scientists who, collectively, hold over 200 years of scientific experience in the field of infrasound and low frequency noise, and its effects of human health. Since 2016, IARO researchers have been recording and analysing acoustical data in and near homes located in the vicinity of onshore wind power plants, in the following countries (alphabetical): Australia, Canada, Denmark, England, France, Germany, Ireland, New Zealand, Northern Ireland, Portugal, Scotland, Slovenia, and The Netherlands. Prior to 2016, all IARO scientists were already working either in acoustics alone or in acoustics and health. All research conducted by IARO is part of the Citizen Science Initiative for Acoustic Characterization of Human Environments (CSI-ACHE).

IV. Ethics Approval

10. This research was performed as part of the Citizen Science Initiative for Acoustic Characterization of Human Environments (CSI-ACHE), the research protocols for which have been approved by the New Zealand Ethics Committee (application number NZEC19_12).

V. SAM Scribe Full Spectrum System for High-Resolution Data Acquisition

11. High-resolution data cannot be obtained with the commonly used and widely commercially available sound level meters. For in-depth and proper scientific study of soundscapes, recordings are required for post-processing analysis.

12. The recording equipment used in the studies documented herein was a SAM Scribe Full Spectrum (FS) system (Soundscape Analytics, Palmerston North, New Zealand), Model Mk2[1]. It is a two-channel device with sampling rates up to 44.1 kHz, that is designed to capture recordings of sonic environments with high precision, especially in the infrasonic and low-frequency bands. Data streams are delivered via USB to a Windows notebook computer and stored as uncompressed wav files to a hard disk. GPS information is stored in the files as metadata, which also include a digital signature. Each wav file corresponds to a 10-minute (600-seconds) recording of the sonic environment. The system can accurately record from 0.1–1000 Hz, as per the manufacturer frequency response of the two electret condenser microphones 2.

13. All measurements reported here cover the range from 0.5–1000 Hz and were captured with a sampling rate of 11.025 kHz. All recordings included a standard reference calibration tone at the start and end, produced with a Type I calibrator (part of the SAM Scribe system) at 1000 Hz/94 dB.

14. Calibration of the SAM Scribe system rests on 1) the manufacturer's frequency-response curve for the microphone and 2) calibration against a certified Larsen-Davis 831 sound level meter in the range of 6.3-1000 Hz.

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[1] Bakker HHC, Rapley BI, Summers SR, Alves-Pereira M, Dickinson PJ. An affordable recording instrument for the acoustical characterisation of human environments. In: Proceedings International Conference Biological Effects of Noise (ICBEN); 18-22 June 2017; Zurich, Switzerland; 2017. No. 3654
http://www.icben.org/2017/ICBEN%202017%20Papers/SubjectArea05_Bakker_P40_3654.pdf

[2] Model No.: EM246 ASSY, Primo Co, Ltd, Tokyo, Japan. Available from: https://www.primo.com.sg/components/

15. The SAM system—including the microphones, EV05 sound card, calibrator, computer and software—is **not a sound level meter** (SLM). It is not primarily used for compliance testing and hence does not carry the type of certification required for such testing.

16. The SAM system provides research-grade recording where the focus is on discovery and analysis rather than compliance testing, which would require class typing to acoustic standards.

17. The manufacturers of the Primo microphone capsules provide test results indicating that the capsules have a level response between roughly 0.5–5000 Hz.

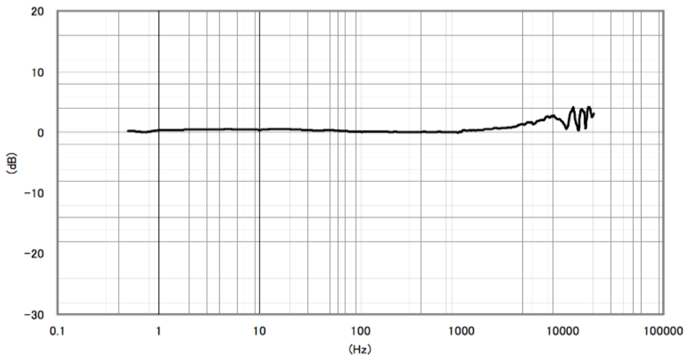

Figure 1: Manufacturer's specification for the Primo microphone capsule used in both the SAM Mk1 and SAM Mk2 systems.

18. The EV05 sound card has been tested against Class 1 SLMs and shown to have a high degree of linearity down to roughly 0.2 Hz. Only SLMs with specialist, infrasound-rated microphones can be used for comparisons below 20 Hz and, even then, the SLMs may only report levels down to several Hertz.

19. The recordings made by the SAM technology are calibrated by including a 1000-hertz, 94-decibel tone from a Class 1 calibrator. Analysis of calibration tones recorded by a Mk1 system over several years indicates that the EV05 sound card maintains an uncalibrated accuracy of roughly ±2 dB.

20. Frequency analysis of the recordings are performed using narrow-band filters 1/36 of an octave wide. These filters meet the requirements of Class 0 filter banks for both ANSI® S1.11-2004 and IEC 61260:1995.

21. As a result of these specifications, the SAM recording technology, and subsequent analysis software, can produce analyses sufficient to determine the characteristics and sound pressure levels of the sound environment to a similar level of accuracy as recordings made by SLMs.

VI. Diaries

22. When the SAM Scribe System is placed in homes for data acquisition, the residents are asked to keep diaries detailing their health-related symptoms, or lack thereof, such as sleep disruption, headaches, nausea, etc. Post-processing analysis investigates the co-existence of features observed in the soundscape and the self-reported symptoms or lack of symptoms. No such diaries were collected during the recordings reported herein.

C. TECHNICAL BACKGROUND FOR LAYPERSONS

I. Wind Power Plants and their Neighbouring Communities

23. It may be surprising to those reading this report that, all over the world, including the UK:

a. Citizens living in the vicinity of onshore wind power plants (WPPs) have been complaining of adverse health effects, also observed in pets and livestock.

b. Citizens living in the vicinity of onshore and offshore WPPs have formed small, grass-roots groups to confront the 'wind industry.'

c. Numerous ongoing legal proceedings are opposing private citizens, or groups of private citizens, who are, themselves, challenging the 'wind industry.'

d. Many of the ongoing and concluded legal proceedings are subjected to non-disclosure agreements, or gag orders.

24. In the UK, situations where residential communities oppose WPPs are not new, and have been ongoing for three decades, since the operation of the first wind turbines in 1991 at Delabole in Cornwall—hub height: 32m, blade length: 17 m. For comparison, in 2021, the Arecleoch WPP turbines in Scotland have a hub height of 83 m, and a blade length of 69 m. Figure 1 is reproduced from industry literature.

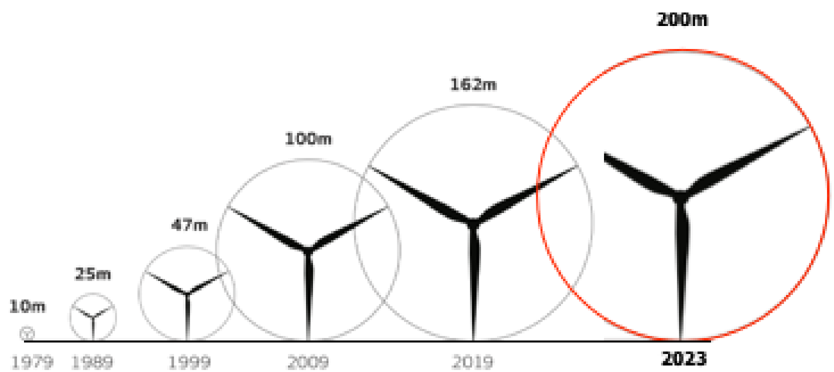

Figure 2: Evolution of the size of wind turbine rotor blades[3]. (Amended to include 200-metre wind turbines.)

25. In addition to the stroboscopic effect (which, in the sole case of wind turbines, is termed 'shadow flicker') and the decreased visual amenity, wind turbines also produce 'noise.'

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3 Vestas Wind Systems A/S, 2019. "EnVentus Platform" Brochure. https://www.vestas.com/en/products/enventus-platform/enventus-platform

26. A part of the 'noise' produced by wind turbines is of a unique type, that is not properly contemplated in current assessment guidance: pulsed infrasound and low frequency noise.

27. The immediate and long-term effects of this unique type of 'noise' on human health are, for the most part, not investigated.

II. ETSU-R-97

28. In the U.K., the document that regulates WPP noise is ETSU-R-97[4]. The 175-page document, titled "The assessment & rating of noise from wind farms," has an opening statement which is fully transcribed below:

> *This report was drawn up under the direction of the Noise Working Group. While the information contained in this report is given in good faith, it is issued strictly on the basis that any person or entity relying on it does so entirely at their own risk, and without the benefit of any warranty or commitment whatsoever on the part of the individuals or organisations involved in the report as to the veracity or accuracy of any facts or statements contained in this report. The views and judgements expressed in this report are those of the authors and do not necessarily reflect those of ETSU, the Department of Trade and Industry or any of the other participating organisations* [5].

29. It might now be interesting to list the people and entities who knowingly co-signed a document of (self-acknowledged) questionable veracity and dubious accuracy[6]:

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4 ETSU-R-97: The assessment and rating of noise from wind farms. The Working Group on Noise from Wind Turbines, Final Report September 1996. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/49869/ETSU_Full_copy__Searchable_.pdf

5 ETSU-R-97, Page 0

6 At least two of the commercial enterprises represented in this Working Group are still closely involved in current wind power plant planning procedures: The Hayes McKenzie Partnership and Hoare Lea and Partners.

Table 1: Members of the Noise Working Group

Mr R Meir, Chairman	DTI
Dr M L Legerton, Secretary	ETSU
Dr M B Anderson	Renewable Energy Systems
Mr B Berry	National Physical Laboratory
Dr A Bullmore	Hoare Lea and Partners
Mr M Hayes	The Hayes McKenzie Partnership
Mr M Jiggins	Carrick District Council
Mr E Leeming	The Natural Power Company Ltd
Dr P Musgrove	National Wind Power Ltd
Mr D J Spode	North Cornwall District Council
Mr H A Thomas	Isle of Anglesey County Council
Ms E Tomalin	EcoGen Ltd
Mr M Trinick	Bond Pearce Solicitors
Dr J Warren	National Wind Power Ltd

30. ***Question*****: Who represented the medical community?**

31. If no medical expertise was relied upon, why is ETSU-R-97 presumed to incorporate the protection of Public Health against wind turbine noise?

32. The answer to this question becomes obvious in the first paragraph of the ETSU's Executive Statement, transcribed below (our bold):

> *This document describes a framework for the measurement of wind farm noise and gives indicative noise levels thought* ***to offer a reasonable degree of protection*** *to wind farm neighbours,* ***without placing unreasonable restrictions on wind farm development or adding unduly to the costs and administrative burdens on wind farm developers*** *or local authorities. The suggested noise limits and their reasonableness have been* ***evaluated with regard to regulating the development of wind energy in the public interest.*** *They have been presented in a manner that* ***makes them a suitable basis for noise-related planning conditions or covenants within an agreement between a developer of a wind farm and the local authority*** *(Executive Summary, page iii).*

33. In conclusion, ETSU-R-97 does not cover health effects that may arise due to WPP noise exposure.

III. Infrasound Considered Non-Existent by Governmental Authorities

34. Considering the antiquity of ETSU-R-97 (originally established in 1997), in 2021 the U.K. Government's Department of Business, Energy and Industrial Strategy (DBEIS) launched a "Scoping review of current onshore wind turbine noise assessment guidance" with the following stated purpose:

> *The purpose of the review is to determine whether the guidance adequately ensures that wind farm turbine noise is managed effectively and consistently in line with current Government policies on noise (…), accounts for contemporary technological and acoustical developments, and (if not), what updates may be necessary to achieve this.*[7]

35. However, "Government policies on noise" were to only include those associated with "Amplitude Modulation"[8] and "Tonality"—two features associated with 'noise' emitted by wind turbines, both of which imply (exclusively) the existence of audible disturbances.

36. Notably, there is no entry for "Infrasound" nor for "Low Frequency Noise," although the item associated with "Amplitude Modulation" may cover some aspects of the audible, low frequency noise emissions.

37. Infrasound exposure can have deleterious effects on human health; this is a decades-old, known fact.

38. With the growing industrialization and mechanization that occurred worldwide in the 1960s, infrasound in the environment began to take its toll on workers and urban citizens. Thus, in 1973, the National Research Council of France organized an International Colloquium entirely dedicated to infrasound[9]. That was fifty years ago. An enormous body of *bona fide* scientific evidence attesting to the pathological effects of infrasound exposure has been produced over these 5 decades, in many different languages.

39. An in-depth presentation of the known health effects caused by infrasound exposure is beyond the scope of this report.

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7 *Scientific Commentary on the UK Government's Department of Business, Energy and Industrial Strategy (DBEIS) "Scoping review of current onshore wind turbine noise assessment guidance."* Document number IARO21-6, December 2021.

8 Amplitude modulation is defined in the DBEIS survey as: "A sound characteristic associated with the regular rotation of the wind turbine blades, something described as 'swishing', 'whooshing', 'whoomphing', or 'thumping'".

9 Pimorov, L, editor. Les Infra-Sons. CNRS Publishing, France: 1974.

IV. Types of Analyses made possible by data acquisition with the SAM Scribe System

Sonogram and Harmonic Analysis

40. This report contains many analyses carried out on recorded data. The two most common are the harmonic analysis and the sonogram.

41. A sonogram essentially plots the energy at many frequencies or pitches against time. A musical scale does the same thing; the height of the note in the stave shows its pitch and the distance along the stave the time.

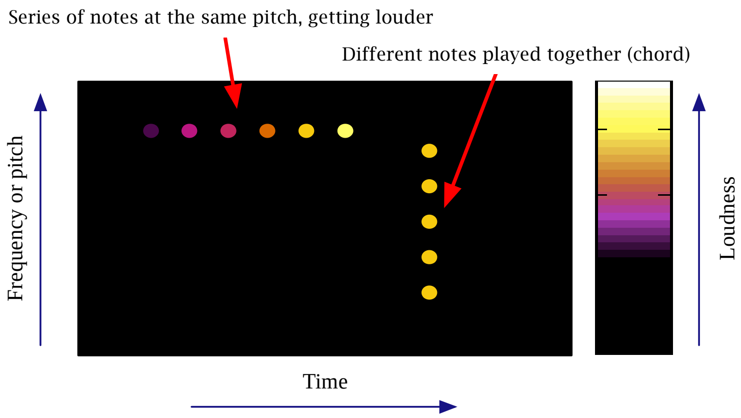

Figure 3: Conceptual representation of a sonogram.

42. Here, the increasing distance vertically represents increasing frequency, or pitch, and distance to the right represents passing time. The colour represents the energy of the sound at the given frequency and time. The scale on the right indicates the 'loudness' of the colours in decibels.

43. The following is a sonogram showing the frequencies from 0.5 Hz (infrasound), through 20 Hz (classical boundary between infrasound and 'audible sound'), up to 1000 Hz, which, musically, is slightly higher than B above middle C.

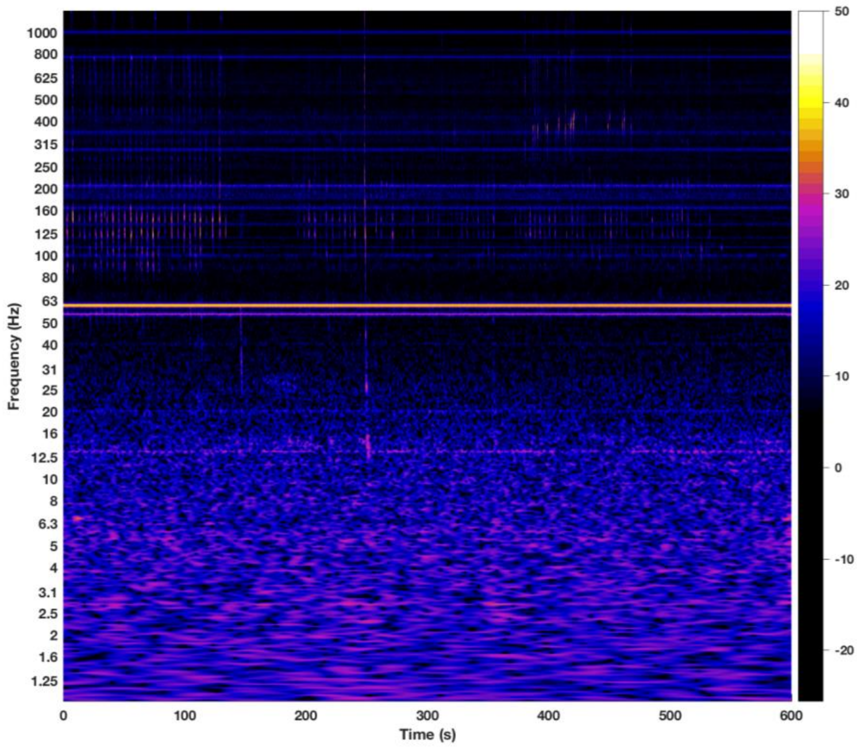

Figure 4: Sonogram of tones and snoring.

44. The narrow horizontal lines are tones (sustained notes) that exist continuously along the entire 10-minute (600 seconds) sample. Each vertical line is a single noise (akin to piano chords). In this case, the multiple vertical lines seen in the upper half of the image correspond to someone snoring. The yellow, horizontal line in the middle is the brightest and therefore the loudest, at about 40 dB.

45. The following figure is the same sonogram but with a time-series plot (top) and a spectrogram (left).

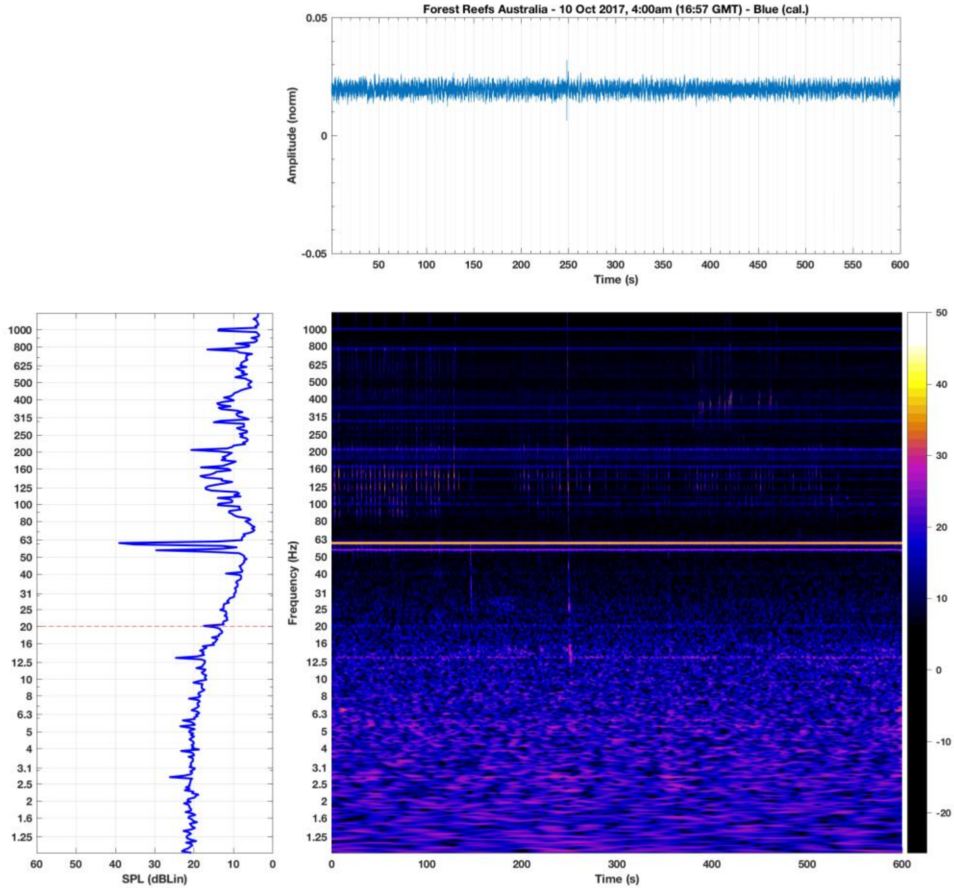

Figure 5: Tryptic of sonogram (bottom right), time-series signal (top) and spectrogram (left).

46. The top plot is the time-series signal, the signal that the microphone is recording. The peaks in the signal are the individual snores, from directly below in the sonogram.

47. The plot on the left is the spectrogram where the energy in each frequency has been summed over the time of the recording. The two peaks between 50 and 63 Hz in the spectrogram align with the two bright lines directly across in the sonogram.

48. The following is a harmonic analysis from a recording sample obtained at Little Garroch, shown on a spectrogram, as in the previous figure (left image), but now rotated to reflect the decibel level along the vertical axis. The peaks identified with red dots form part of one or more harmonic series.

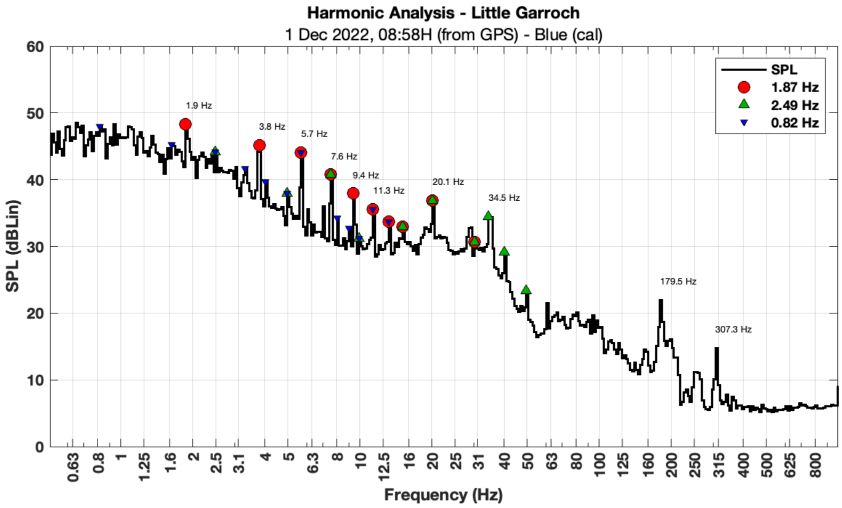

Figure 6: Harmonic analysis of a recording from Little Garroch.

49. A harmonic series has peaks at frequencies that are whole multiples of a fundamental frequency. The previous figure shows two major harmonic series; one with a 1.87-hertz fundamental frequency (red dots) and one at a 2.49-hertz fundamental frequency (green triangles). The height of the peaks above the background show that these harmonic series will dominate the recording. This can be seen in the matching sonogram in the following figure as horizontal lines in the lower half of the image.

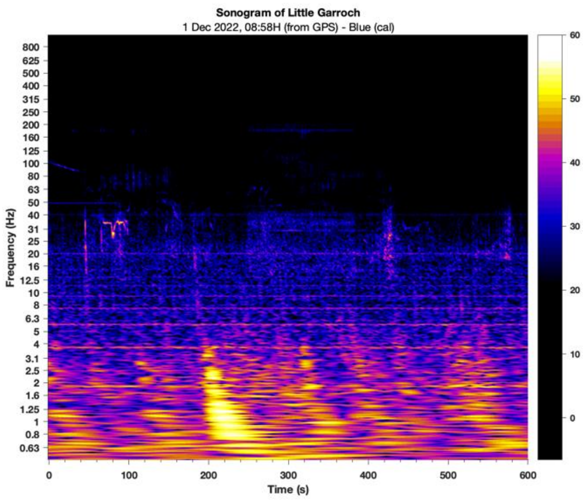

Figure 7: Sonogram of the recording shown in the previous figure.

50. Harmonic series are not common in nature and are usually linked to human activity of some sort, such as a musical instrument being played.

51. The following figure compares sonograms taken in a natural environment (Romo Island, Denmark, 13 December 2016) and in a residence close to Dersalloch (5 January 2023) where the acoustical output of the operational wind turbine is captured as a distinct mathematical pattern: a harmonic series.

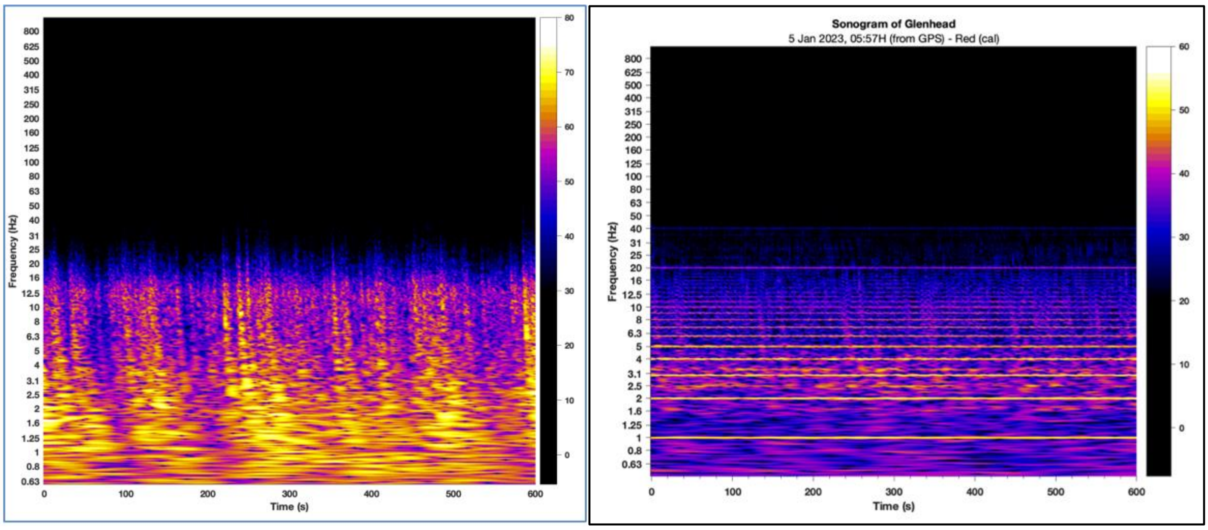

Figure 8: Sonograms comparing a natural environment to one containing wind turbine acoustic signature. (Left) Sonogram of the beachfront at Romo Island, Denmark (13 December 2016, approximately 01:00H), reflecting the periodicity of ocean waves hitting the beach. (Right) Sonogram in a residence near Dersalloch (5 January 2023, approximately 06:00H) showing the acoustical output of an operational wind turbine, in the form of straight, evenly spaced, bright horizontal lines, i.e., reflecting the presence of harmonic series.

Harmonic Prominence and Harmonic Sound Pressure Level

52. IARO has created two white papers on the analysis of harmonic prominence and harmonic sound pressure level.[10,11]

53. Harmonic prominence metrics seek to establish new measures with possible health-related significance, involving the existence of a harmonic series above the background noise. Two metrics are considered: the peak harmonic prominence, P_{peak}, and the total harmonic prominence, P_{tot}.

10 White Paper on the Harmonic Prominence Measure, IARO21-3, v6, 2021

11 White Paper on the Harmonic Series Metrics, IARO23-1, 2023

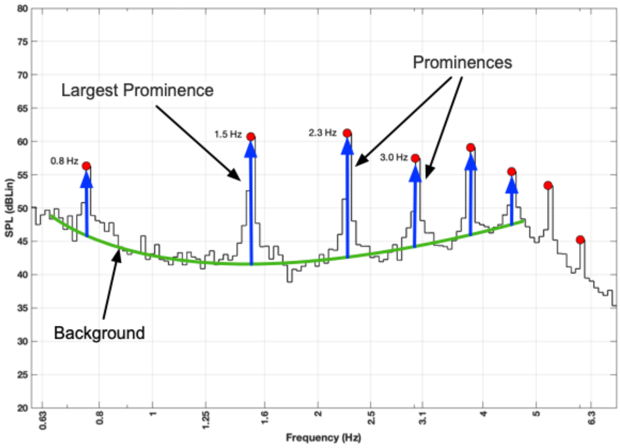

Figure 9: Representation of the prominence of spectral peaks above the background noise,

54. The P_{peak} is the largest height of a harmonic peak above the background (prominence). This can be measured for all the harmonic series in a recording or for individual harmonic series. The more restrictive P_{harm} limits this to the peaks between 0.5 and 5 Hz.

55. The P_{tot} is energy sum of the prominence of all the harmonic peaks identified. This can be measured for all the harmonic series present, in which case it will be the largest P_{tot} of all the harmonic series present.

56. The harmonic sound pressure level metrics seek to measure the effect of the harmonic series on animals and people. It therefore uses the total height of the harmonic peaks. The two metrics, H_{peak} and H_{tot}, are analogous to the harmonic prominence metrics, differing only in the fact that they use the total height of the peaks rather than their prominence over the background.

Harmonic Series Histogram

57. The pervasiveness of harmonic series in recordings can be visualised by plotting a histogram of the number of times harmonic series appear in recordings. This can be seen in the following figure.

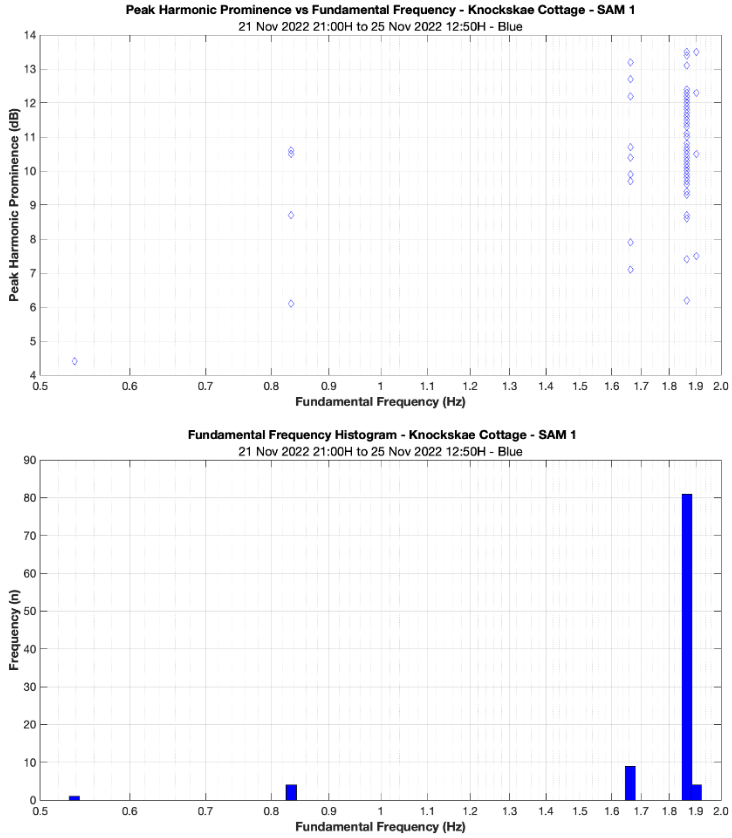

Figure 10: Peak harmonic prominence (top) and number of recordings (bottom) against fundamental frequency in all recordings from Knockskae Cottage from 21 November to 25 November 2022. (The dominant harmonic series for each recording is used.)

58. The upper plot shows the peak harmonic prominence for every recording against the fundamental frequency of its harmonic series. Larger peak harmonic prominences mean that the harmonic series is more dominant in the frequency spectrogram.

59. The lower plot shows the number of recordings that contain the given harmonic series. The more recordings that contain a given harmonic series as the most prominent, the more pervasive that series is throughout the recording period.

Wind Roses

60. Meteorological wind roses display wind speed as a frequency histogram wrapped around a circle. That is, each bar of the histogram indicates the number of intervals where the wind came from that direction with a wind speed within the given range.

61. Any metric can be plotted in the same way by replacing the speed of the wind with the given metric. The following figure shows a P_{peak} wind rose where the metric plotted is the P_{peak}. The length of each coloured section of a bar identifies the number of 10-minute recordings over the recording period that had a P_{peak} value within a 5-decibal window when the wind was coming from a given direction. The direction of the bar identifies the wind direction, and the colour of the section identifies the P_{peak} window. Since the sections of each bar are stacked, the numbers on the circles indicate the cumulative number of 10-minute recordings.

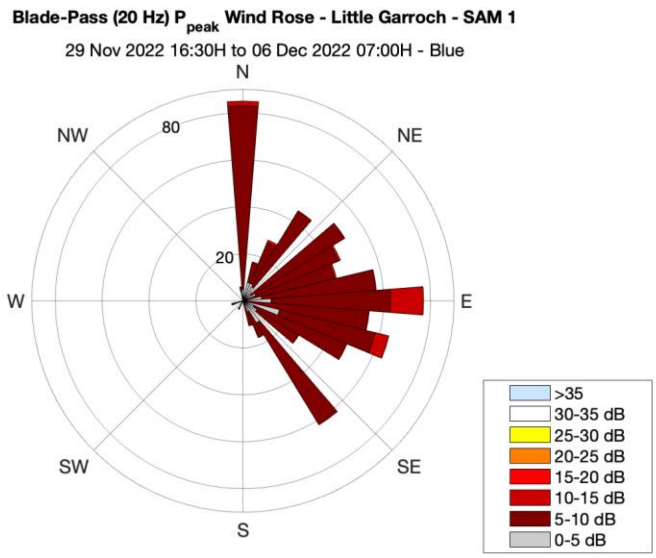

Figure 11: A P_{peak} wind rose for the 20-hertz harmonic series at Little Garroch.

62. The relative lengths of the bar sections are the proportion of 10-minute recordings compared to the total number. In this wind rose the wind varies between north and southeast over the recording period. For most of the recording periods the 20-hertz tone was present and had a peak prominence of more than 5 dB (brown and red sections). Higher prominences of 10–15 dB were seen mostly when the wind was from the west or west-southwest (red sections).

Time-of-Day Plots

63. The metrics defined for harmonic series can also be plotted the time of day against the day, as seen in the following figure.

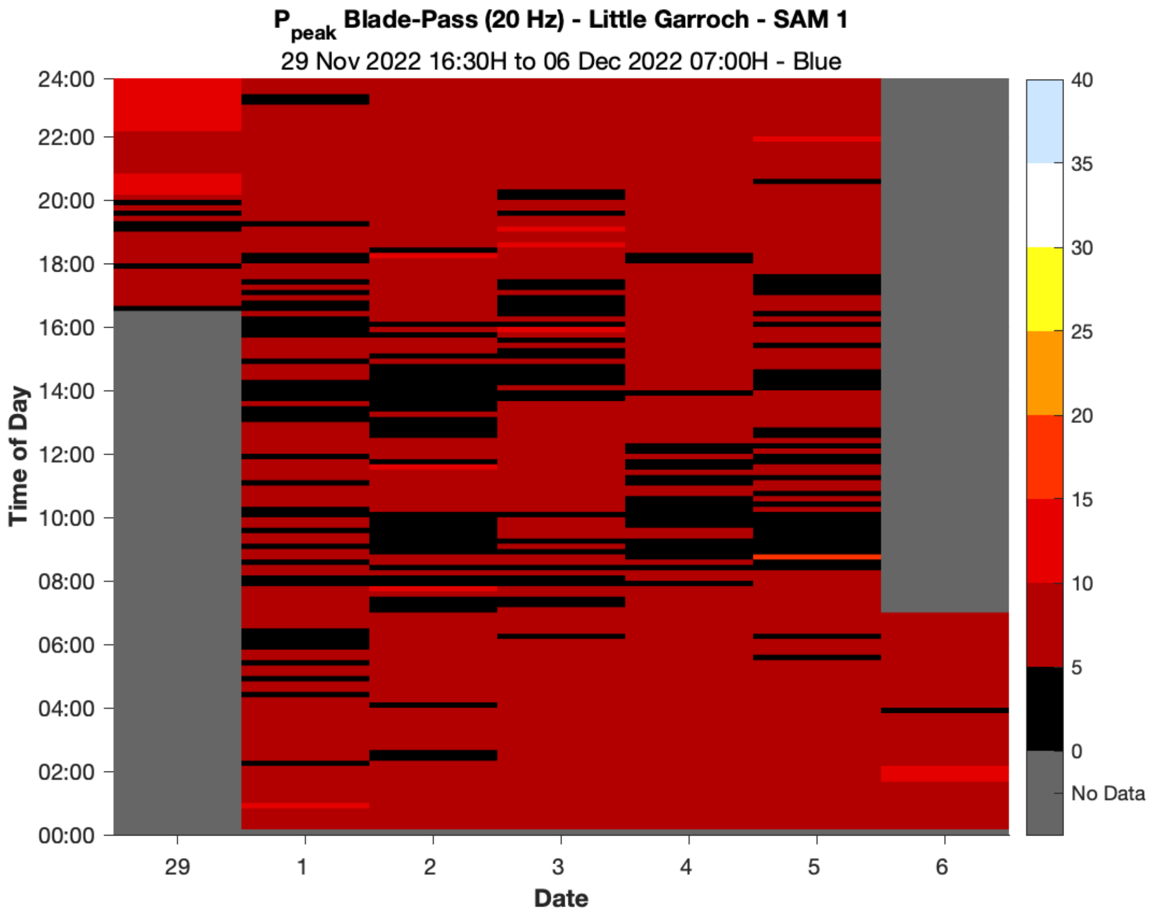

Figure 12: Time-of-day plot for Little Garroch from 29 November to 6 December 2022.

64. Each 10-minute recording is represented as a horizontal bar within a day (across the plot) at a given time (vertically upwards). The colour of the bar indicates the value of the metric for the recording within one of the 10-decibel bins shown in the legend on the right.

65. In this plot a 20-hertz tone is present throughout the recording period, usually between 5 and 10 dB above the background. During the daytime hours it is more likely to drop below 5 dB, or disappear, as shown by the black sections.

Waveform analysis

66. The waveform of a harmonic series shows the shape of the time-series signal that contains the harmonic series. This changes the character of the sound more than its sound level.

67. Two types of analyses can be performed.

68. The first—the synthetic-waveform method—filters the recording at the frequencies of the harmonic peaks and then adds all these filtered signals together to create a synthetic waveform. An example is shown in Wind-Turbine Acoustic Signature, WTAS, below.

69. The second—the averaged-waveform method—takes a template waveform and looks for this template at set intervals in the time series. It then averages all those instances where the difference between the signal and the template are considered small enough. An example is also shown in Wind-Turbine Acoustic Signature, WTAS, below.

70. When several wind turbines are operating the waveform will be a more complex shape, involving the sum of all the individual waveforms. Experience has shown that there is usually one turbine whose WTAS predominates over the others.

V. Wind-Turbine Acoustic Signature, WTAS

71. Wind-turbine acoustic signature (WTAS) is a feature produced by all wind turbines in various noise levels and frequencies.

72. In the frequency domain it is a harmonic series of peaks with the fundamental being at the frequency at which the blades pass in front of the tower. The frequency at which this occurs is called the blade-passing frequency (BPF).

73. In a time-series signal it is a series of pulses that occur at the same rate as the BPF.

74. The pulses can either be positive (an increase in pressure), negative (a decrease in pressure) or a dipole (a negative pulse followed by a positive pulse).

75. An example is given in the following figure from Glenhead.

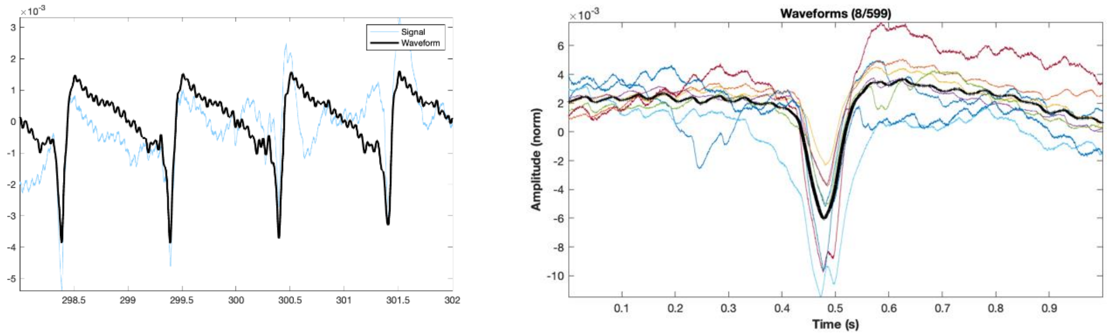

Figure 13: Synthetic waveform (left) and averaged waveform (right) from the Red microphone at Glenhead from 23:47H 4 January 2023. This shows a section at the middle of the recording.

76. The synthetic waveform (left) shows predominant dips in the time series that occur every 1 second, the BPF of the wind turbine which was the source of the disturbance. The averaged waveform (right) shows the 8 waveforms (colours) chosen from the 599 1-second intervals in the recording and the averaged waveform (black). (Note: The ripples seen in both the waveforms are from a 20-hertz signal that is also present.)

77. In a spectrogram WTAS is seen as a harmonic series with the fundamental frequency being the BPF. This can be seen in the following figure.

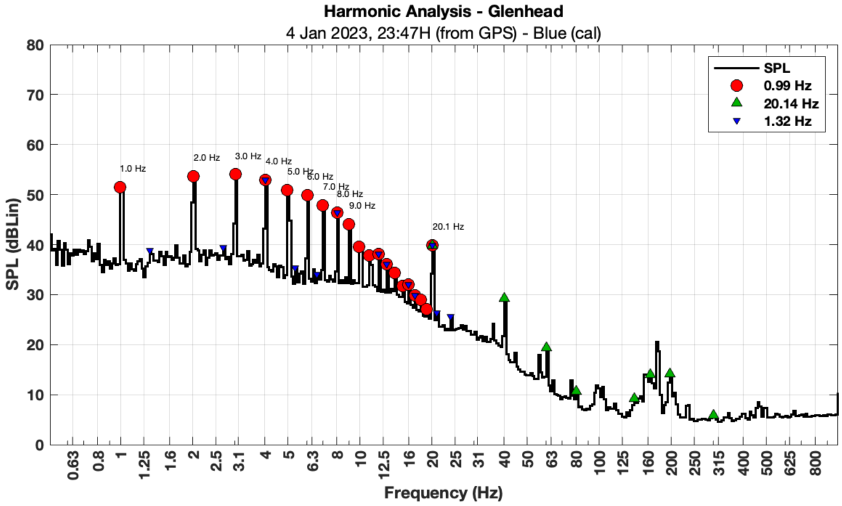

Figure 14: WTAS in a recording from Glenhead.

78. This is the same recording as in the previous figure and shows the WTAS as a harmonic series with a fundamental frequency of 1 Hz (red dots), suggesting a wind-turbine model that rotates with a 1-hertz BPF. The 20-hertz harmonic series (green triangles) is not WTAS as there are no wind turbines with a BPF of 20 Hz.

VI. A-Weighting vs Unweighted

79. Acousticians normally work with A-weighted sound as this is supposed to align with the human hearing system. In this system the level of each frequency is adjusted to account for the fact that humans are not equally sensitive to all frequencies.

80. Two examples show the effect of this method on analyses in the infrasound and low-frequency parts of the acoustic spectrum.

81. The following figure shows a spectrogram from Glenhead with each frequency band segmented into ⅓ of an octave.

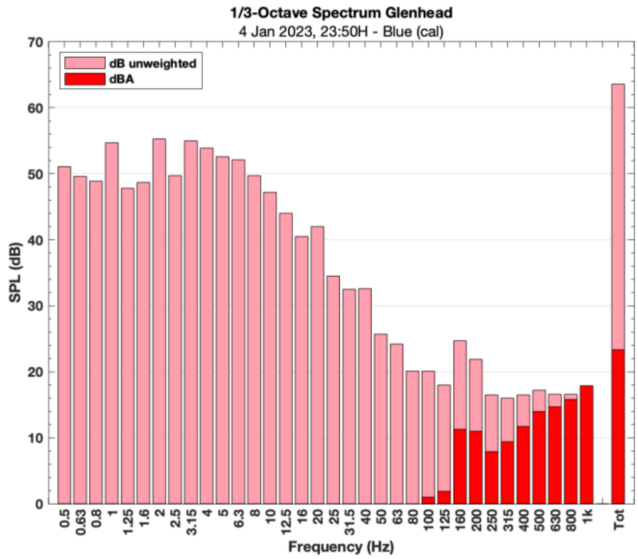

Figure 15: Spectrogram in ⅓ octaves for the Blue microphone from Glenhead from 23:50H 4 January 2023. Unweighted (pink) and A-weighted (red). The total energy is shown in the final bar on the right.

82. The difference between the unweighted and A-weighted spectra is profound, showing very clearly that any analysis of sound in the infrasound or low-frequency parts of the spectra must not be carried out with A-weighting. The total sound level is roughly 40 dB less using A-weighting (rightmost bar).

83. The following figure compares the screenshots taken directly from the SAM system while recording at Glenhead (4 January 2023, 16:20H), showing the levels registered by the blue and red microphones with the A-weighting applied (left) and with no weighting, or unweighted (right).

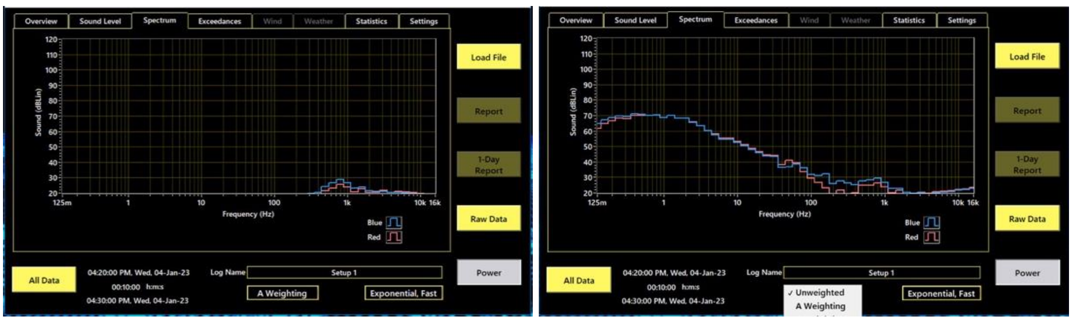

Figure 16: Screenshots of the SAM System while recording at Glenhead (4 January 2023, 16:20H), showing the levels registered by the blue and red microphones with the A-weighting system applied (left) and unweighted (right).

84. Corroborating the visual data presented above, by imposing the A-weighting on data acquisition, a large amount of information is excluded from consideration. Very low levels of audible noise are seen, and nothing in the lower frequencies (left) while the same recording data, but unweighted, shows the full acoustic environment at this location (right).

D. BACKGROUND

85. Within the context of CSI-ACHE, soundscape recordings were acquired in South Ayrshire (Dailly, Straiton, and Knockcronal areas). Several applications for the installation of WPPs in these locations are pending. The goal of the recordings is to collect baseline information within these soundscapes in anticipation of more WPPs being granted consent.

86. All recordings were conducted by Susan Crosthwaite and Grosvenor Consultancy, researchers operating the SAM system and drawing upon the expertise and experience of IARO.

E. RECORDINGS

87. Recordings were taken at the following locations and times during late 2022 and early 2023.

Table 2: SAM 1 recordings and locations.

Location	Date	Recording Time	Microphone Positions
Knockskae	14 Nov 2022	1-hour	Both in Bedroom
Knockskae Cottage	21–25 Nov 2022	Continuous over days	Both in Bedroom
Glenalla Farm	25–29 Nov 2022	Continuous over days	Both in Bedroom
Little Garroch	29 Nov–6 Dec 2022	Continuous over days	Both in Art Studio
Tairlaw House	21–29 Dec 2022	Continuous over days	Both in Work Studio
Glenhead	4–7 Jan 2023	Continuous over days	Both in Bedroom
Glenhead	10 Mar 2023	4-hours	Bedroom & Outside
Glenapp Castle	13–14 Mar 2023	Overnight	Bedroom & Bathroom
Glengennet	20 Mar 2023	3-hours	Bedroom & Hallway
Glengennet	24–25 Mar 2023	Overnight	Bedroom & Hallway
Barnfield	3 Apr 2023	4-hours	Bedroom & Garden
High Tralorg	12 Apr 2023	45-min	Both Outside

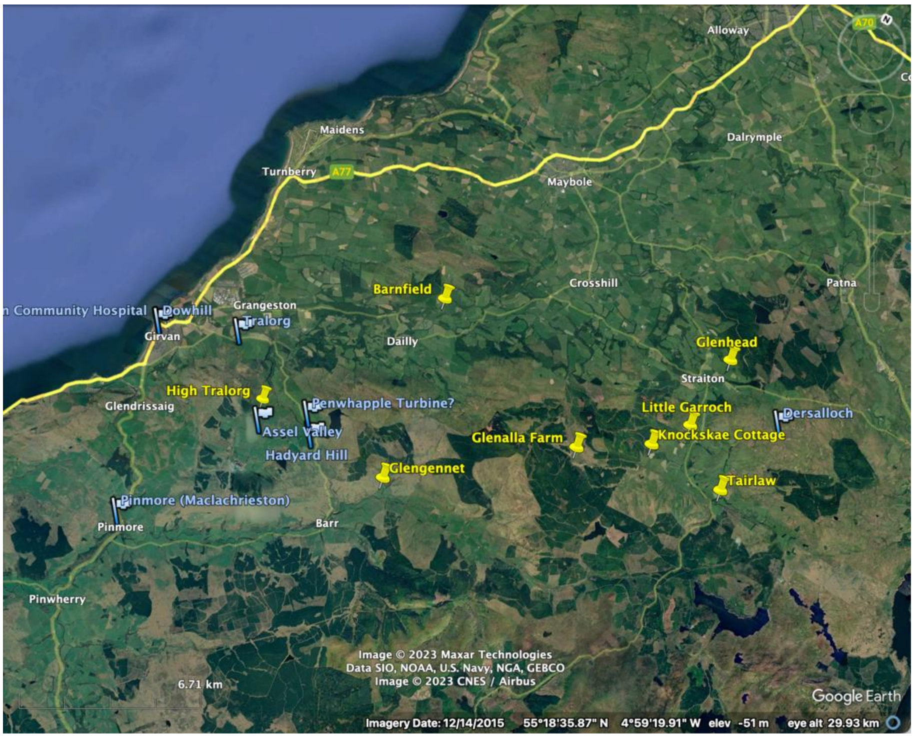

Figure 17: Recording locations (yellow) and nearby WPPs (blue). (Google Earth Pro.)

88. Microphones were mounted on stands, 1.5 m from the ground and placed well away from objects and walls. Wind shields were used, and calibration tones were recorded at the beginning and end of all recordings.

Knockskae

89. The following figure shows harmonic analyses (top) and sonograms (bottom) from the Blue microphone (left) and Red microphone (right). They show two major harmonic series with fundamental frequencies at 1 Hz and 20 Hz. These are shown as red dots and green triangles, respectively, in the upper plots and as horizontal lines in the lower plots.

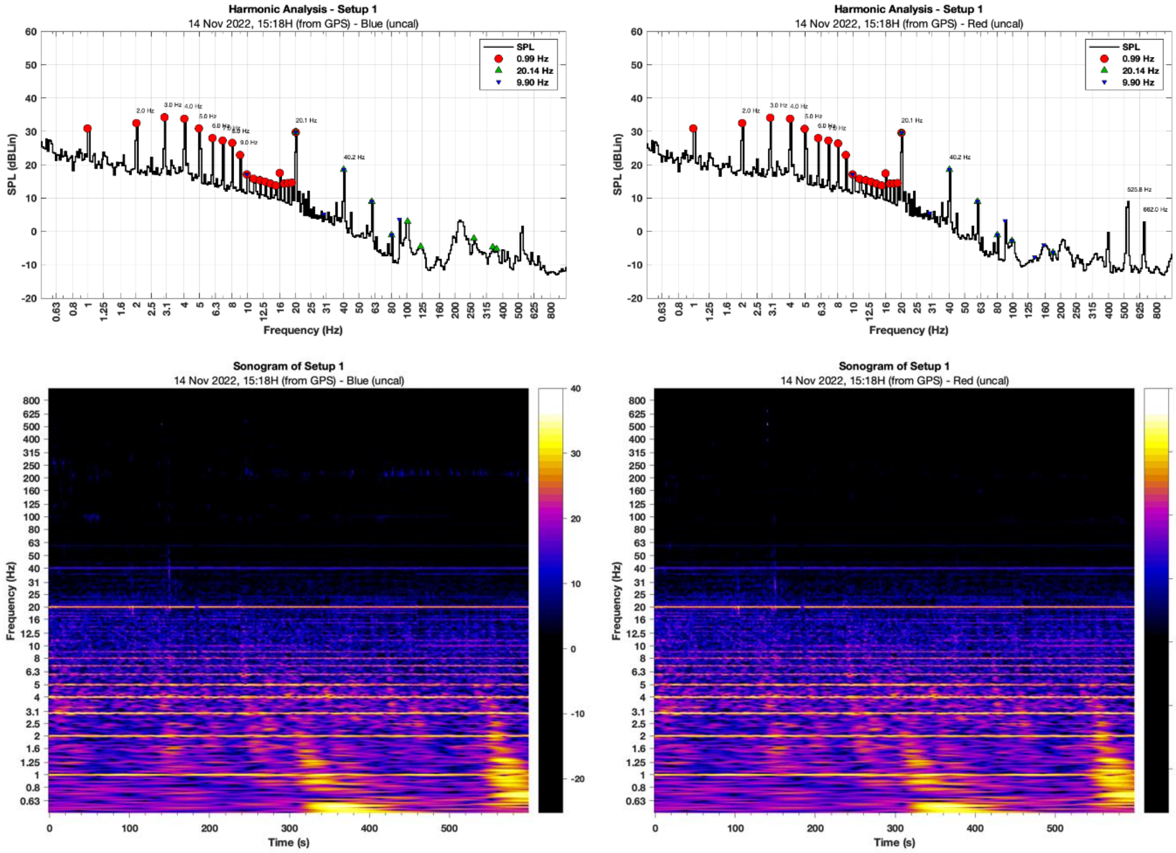

Figure 18: Harmonic analyses (top) and sonograms (bottom) for Knockskae, 15:20H, 14 November 2022. Blue microphone (left) and Red microphone (right).

Knockskae Cottage

90. Analysis of the fundamental-frequency histogram (see **Error! Reference source not found.**) for the period showed only one pervasive harmonic series in the range of 0.5 to 2 Hz, namely at 1.87 Hz. Harmonic series at 1.66 Hz and 0.83 Hz were also present.

91. The following figure shows harmonic analyses (top) and sonograms (bottom) from the Blue microphone (left) and Red microphone (right). They show two major harmonic series with fundamental frequencies at 1.87 Hz and 20 Hz. These are shown as red dots and green triangles, respectively, in the upper plots and as horizontal lines in the lower plots.

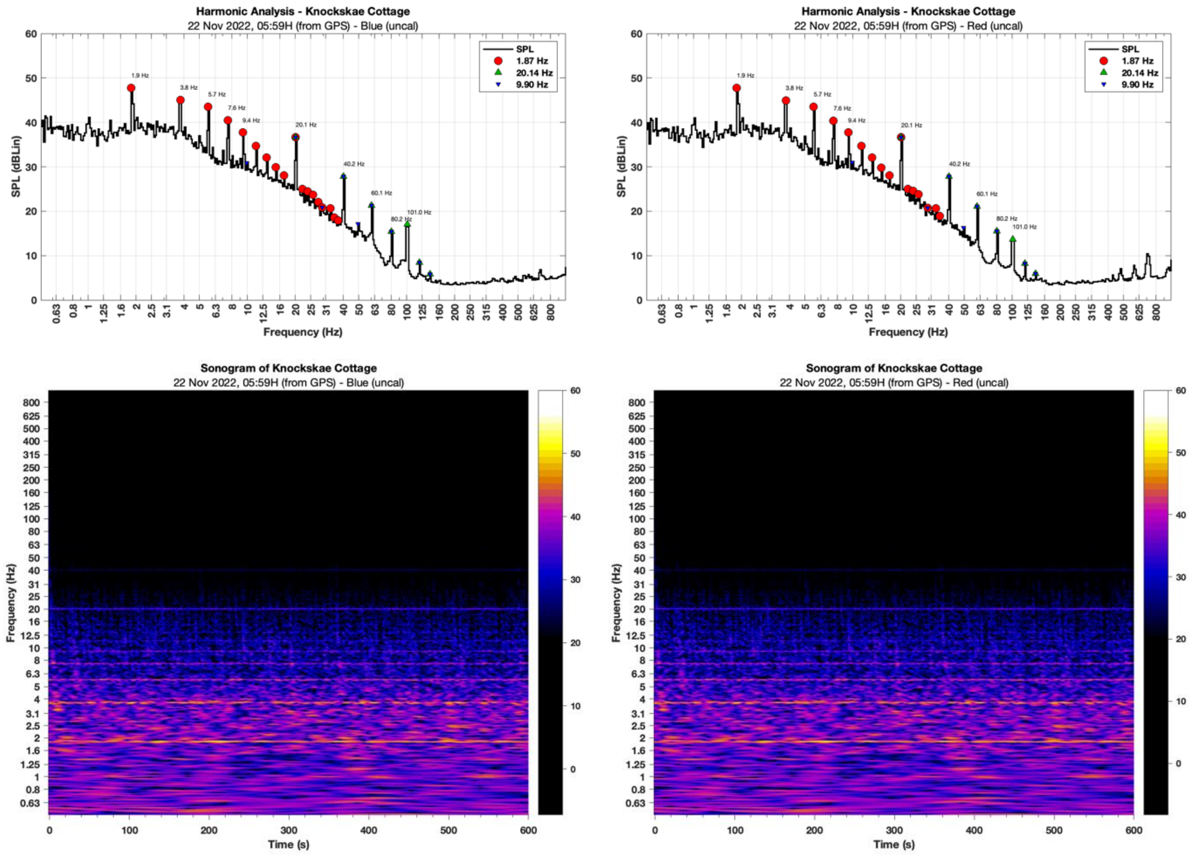

Figure 19: Harmonic analyses (top) and sonograms (bottom) for Knockskae Cottage, 06:00H, 22 November 2022. Blue microphone (left) and Red microphone (right).

92. The following figure shows harmonic analyses (top) and sonograms (bottom) from the Blue microphone (left) and Red microphone (right). There are now three major harmonic series with fundamental frequencies at 1.87 Hz, 20 Hz and 1.66 Hz. These are shown as red dots, green triangles, and as blue, inverted triangles, respectively, in the upper plots and as horizontal lines in the lower plots.

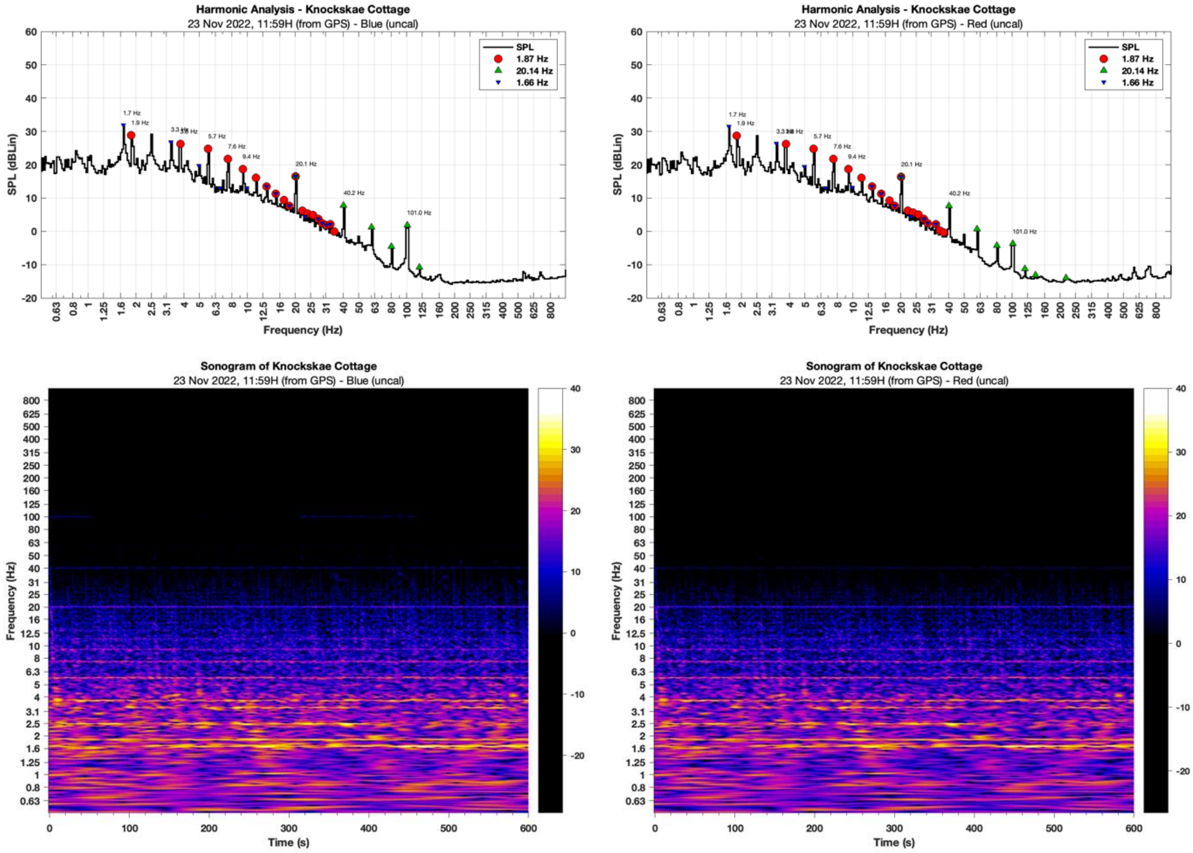

Figure 20: Harmonic analyses (top) and sonograms (bottom) for Knockskae Cottage, 12:00H, 23 November 2022. Blue microphone (left) and Red microphone (right).

93. Time-of-day plots of peak harmonic prominence are shown in the following figure for the 0.833-, 1.66- and 20-hertz harmonic series over the duration of the recording period (Blue microphone only).

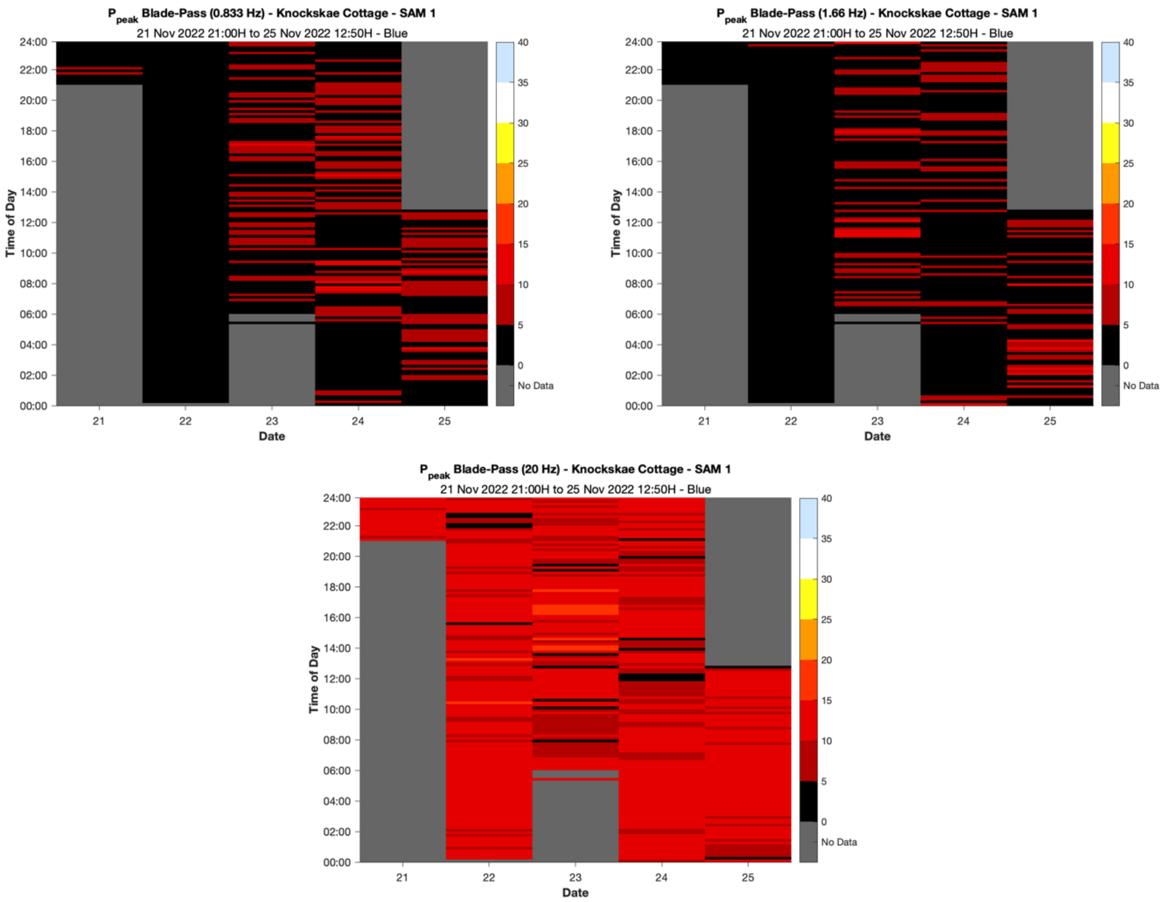

Figure 21: Time-of-day plots for Knockskae Cottage from 21 to 25 November 2022 for the 0.833-hertz (top-left), 1.66-hertz (top-right), and 20-hertz (bottom) harmonic series.

Glenalla Farm

94. Analysis of the fundamental-frequency histogram (see **Figure 10**) for the period showed only one pervasive harmonic series in the range of 0.5 to 2 Hz, namely at 1.87 Hz.

95. The following figure shows harmonic analyses (top) and sonograms (bottom) from the Blue microphone (left) and Red microphone (right). There are three major harmonic series with fundamental frequencies at 1.87 Hz, 20 Hz and 2 Hz. These are shown as red dots, green triangles, and as blue, inverted triangles, respectively, in the upper plots and as horizontal lines in the lower plots.

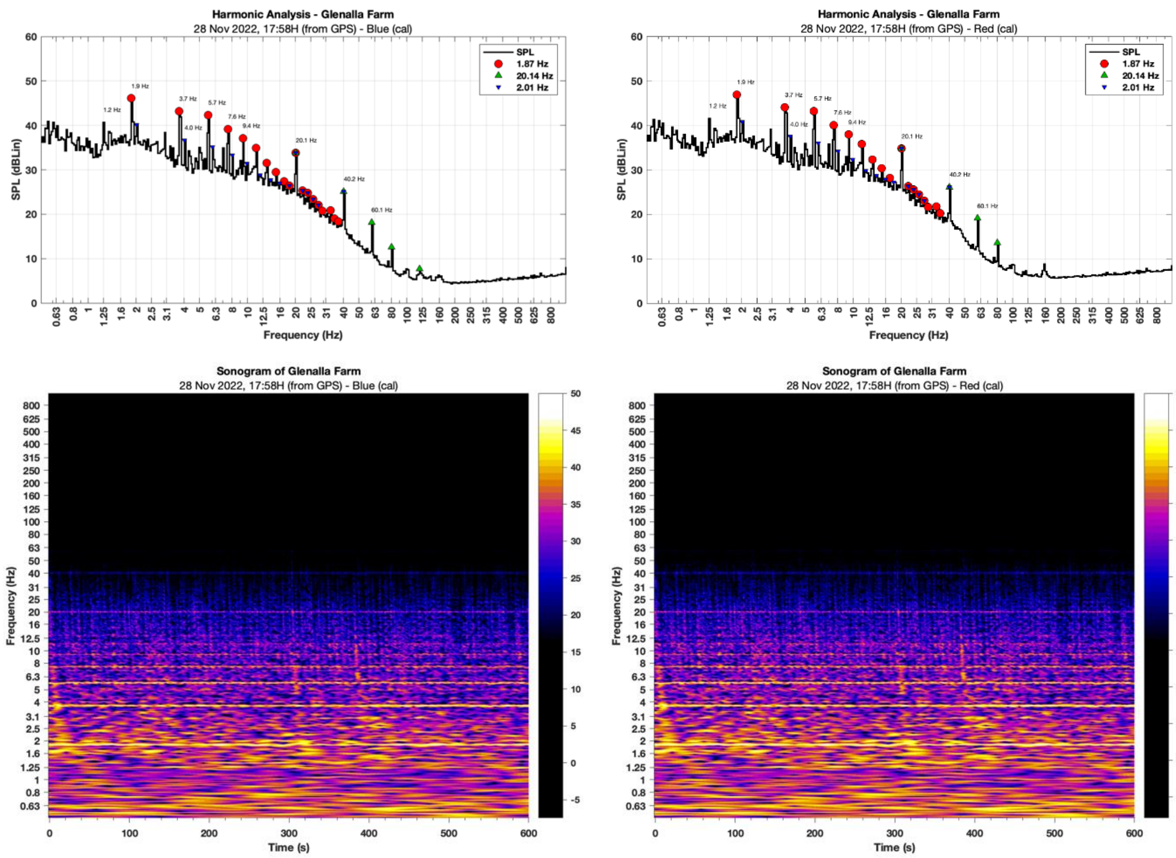

Figure 22: Harmonic analyses (top) and sonograms (bottom) for Glenalla Farm 18:00H, 28 November 2022. Blue microphone (left) and Red microphone (right).

96. Time-of-day plots of peak harmonic prominence are shown in the following figure for the 1-, 1.87- and 20-hertz harmonic series over the duration of the recording period (Blue microphone only).

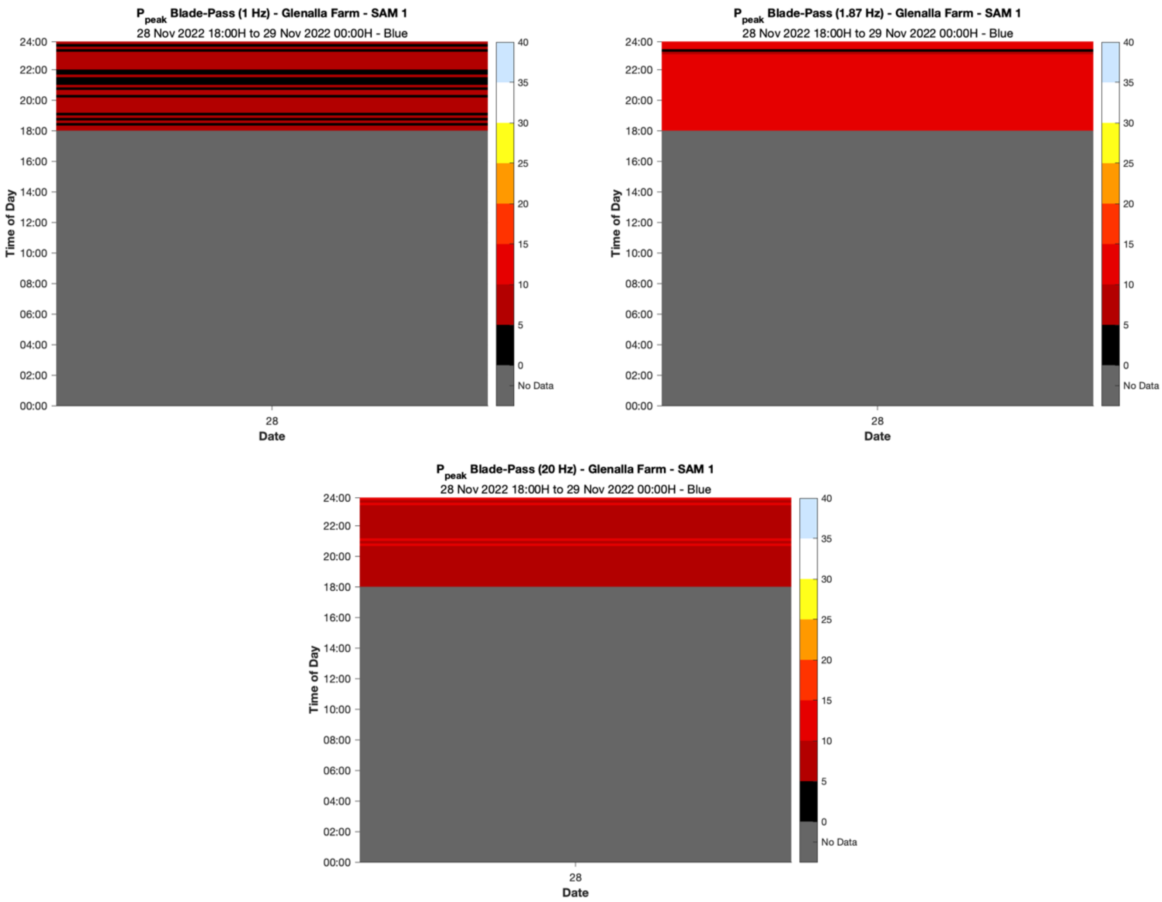

Figure 23: Time-of-day plots for Glenalla Farm on 28 November 2022 for the 1-hertz (top-left), 1.87-hertz (top-right), and 20-hertz (bottom) harmonic series.

Little Garroch

97. Analysis of the fundamental-frequency histogram (see **Figure 10**) for the period showed only one pervasive harmonic series in the range of 0.5 to 2 Hz, namely at 1.87 Hz.

98. The following figure shows harmonic analyses (top) and sonograms (bottom) from the Blue microphone (left) and Red microphone (right). There are three major harmonic series with fundamental frequencies at 1.87 Hz, 20 Hz and 1 Hz. These are shown as red dots, green triangles, and as blue, inverted triangles, respectively, in the upper plots and as horizontal lines in the lower plots.

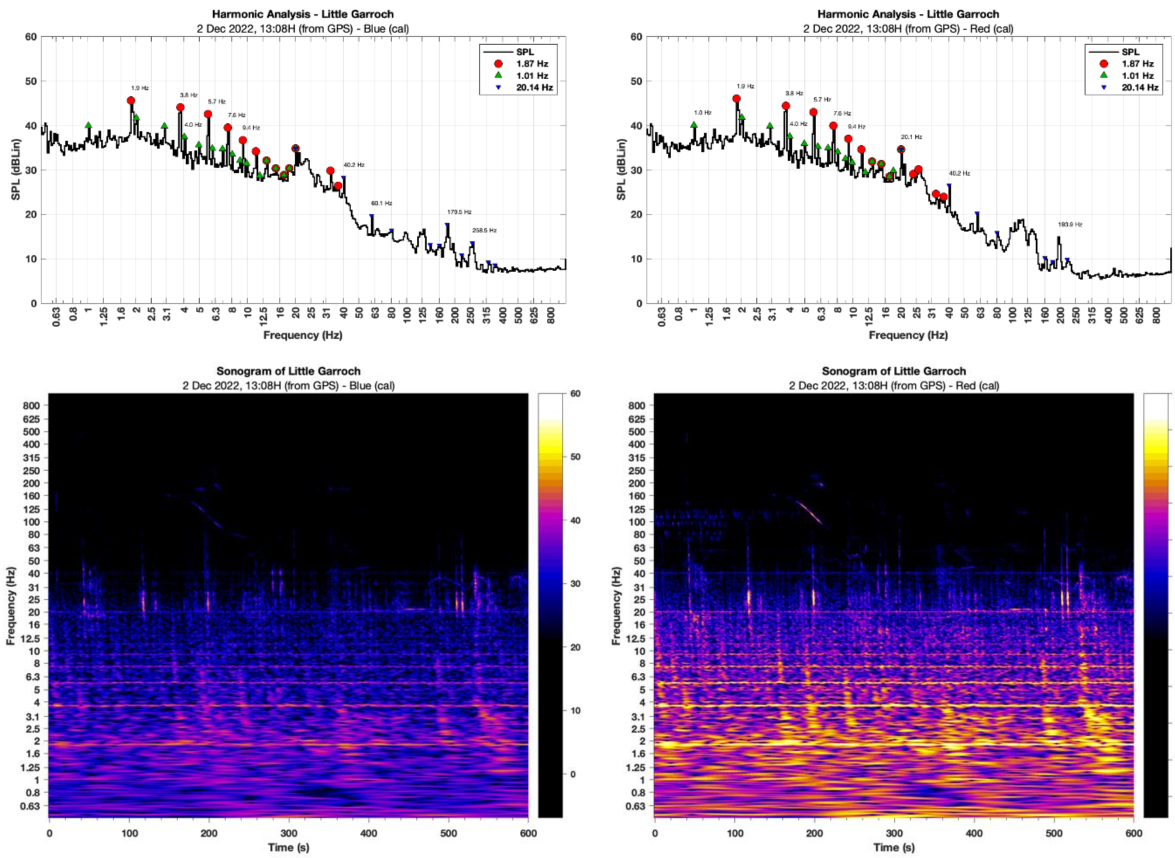

Figure 24: Harmonic analyses (top) and sonograms (bottom) for Little Garroch13:10H, 2 December 2022. Blue microphone (left) and Red microphone (right).

99. Time-of-day plots of peak harmonic prominence are shown in the following figure for the 1-, 1.87- and 20-hertz harmonic series over the duration of the recording period (Blue microphone only).

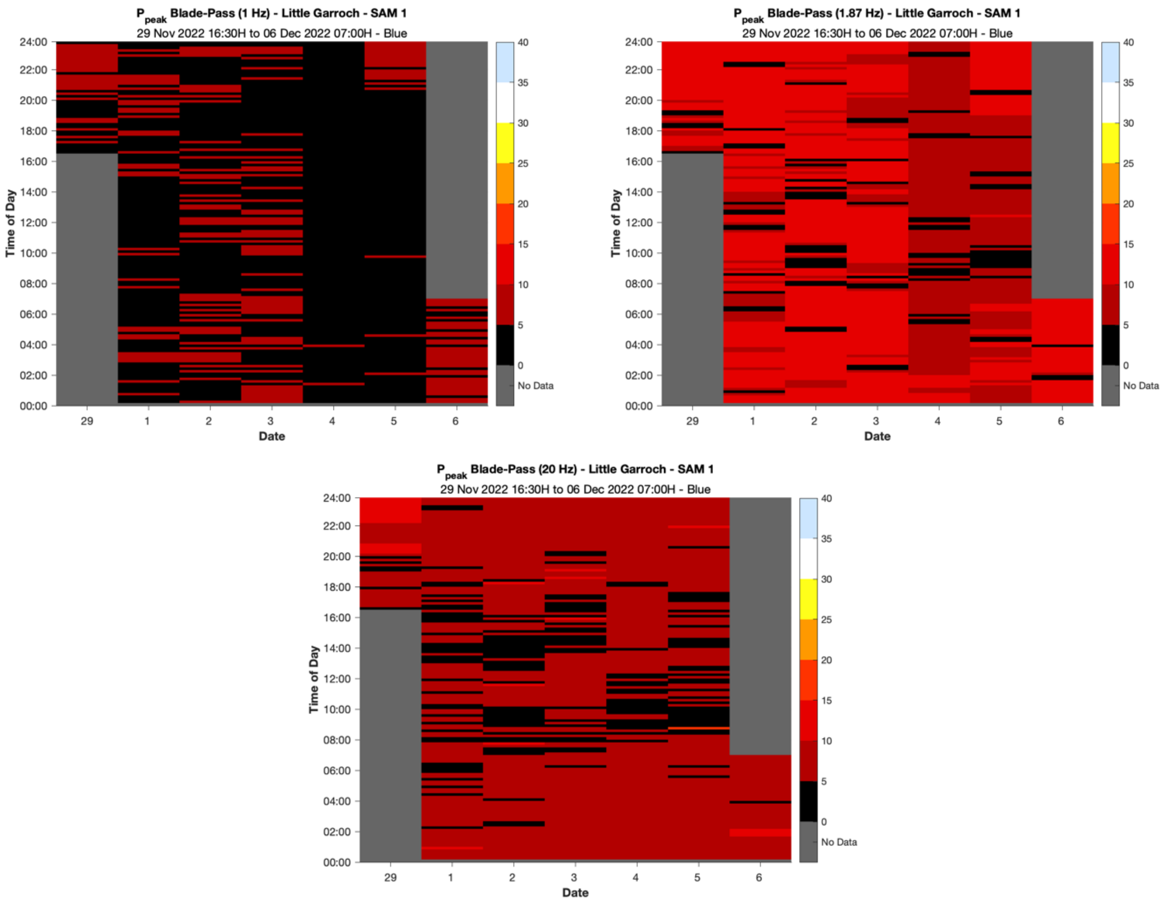

Figure 25: Time-of-day plots for Little Garroch from 29 November to 6 December 2022 for the 1-hertz (top-left), 1.87-hertz (top-right), and 20-hertz (bottom) harmonic series.

Tairlaw House

100. Analysis of the fundamental-frequency histogram (see **Figure 10**) for the period showed three pervasive harmonic series in the range of 0.5 to 2 Hz, namely at 0.73, 0.83 and 1.66 Hz. Of these, the 0.73-hertz series was the most prominent and the most pervasive.

101. The following figure shows harmonic analyses (top) and sonograms (bottom) from the Blue microphone (left) and Red microphone (right). There are two major harmonic series with fundamental frequencies at 0.83 Hz, and 0.73 Hz. These are shown as red dots, and green triangles, respectively, in the upper plots and as horizontal lines in the lower plots.

102. There is also a 100-hertz harmonic series in the recording from the Blue microphone (left), which can be assumed to be due to an appliance within the house.

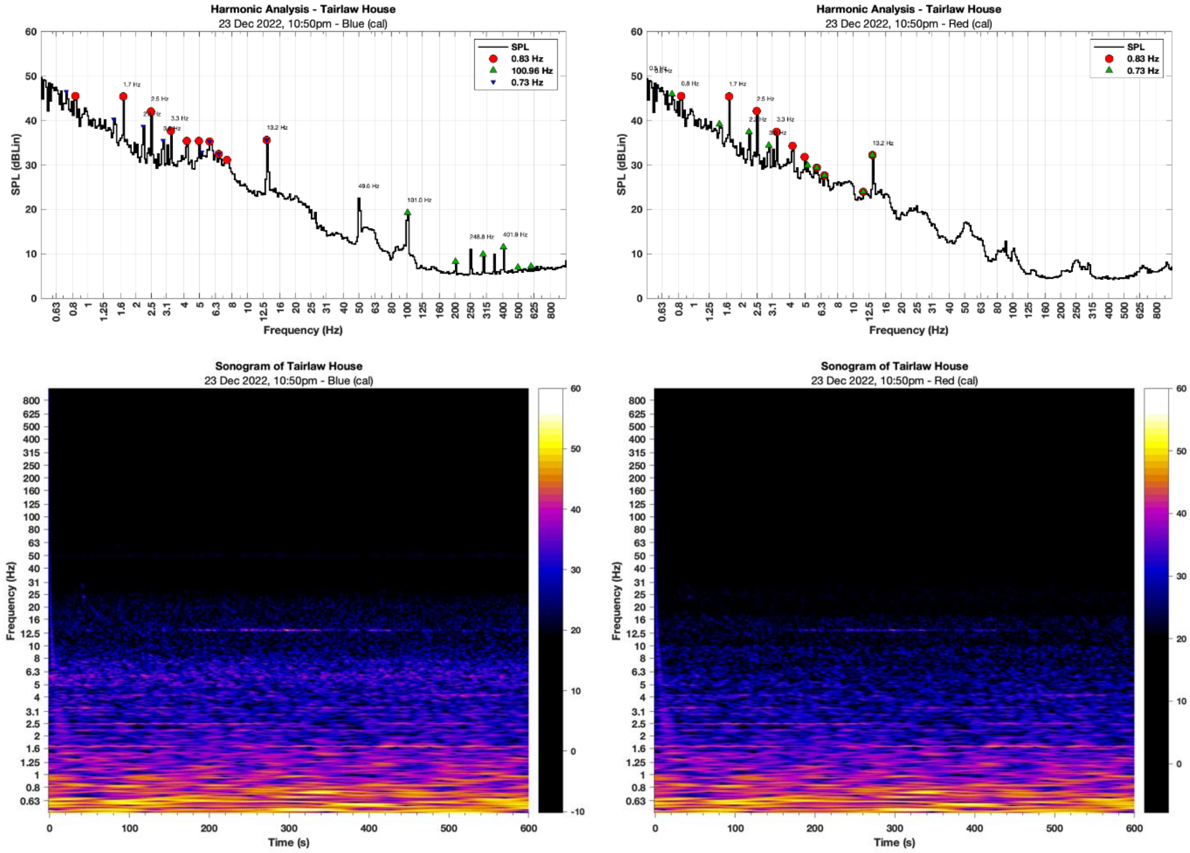

Figure 26: Harmonic analyses (top) and sonograms (bottom) for Tairlaw House 22:50H, 23 December 2022. Blue microphone (left) and Red microphone (right).

103. Time-of-day plots of peak harmonic prominence are shown in the following figure for the 0.73-, 0.833- and 1.66-hertz harmonic series over the duration of the recording period (Blue microphone only).

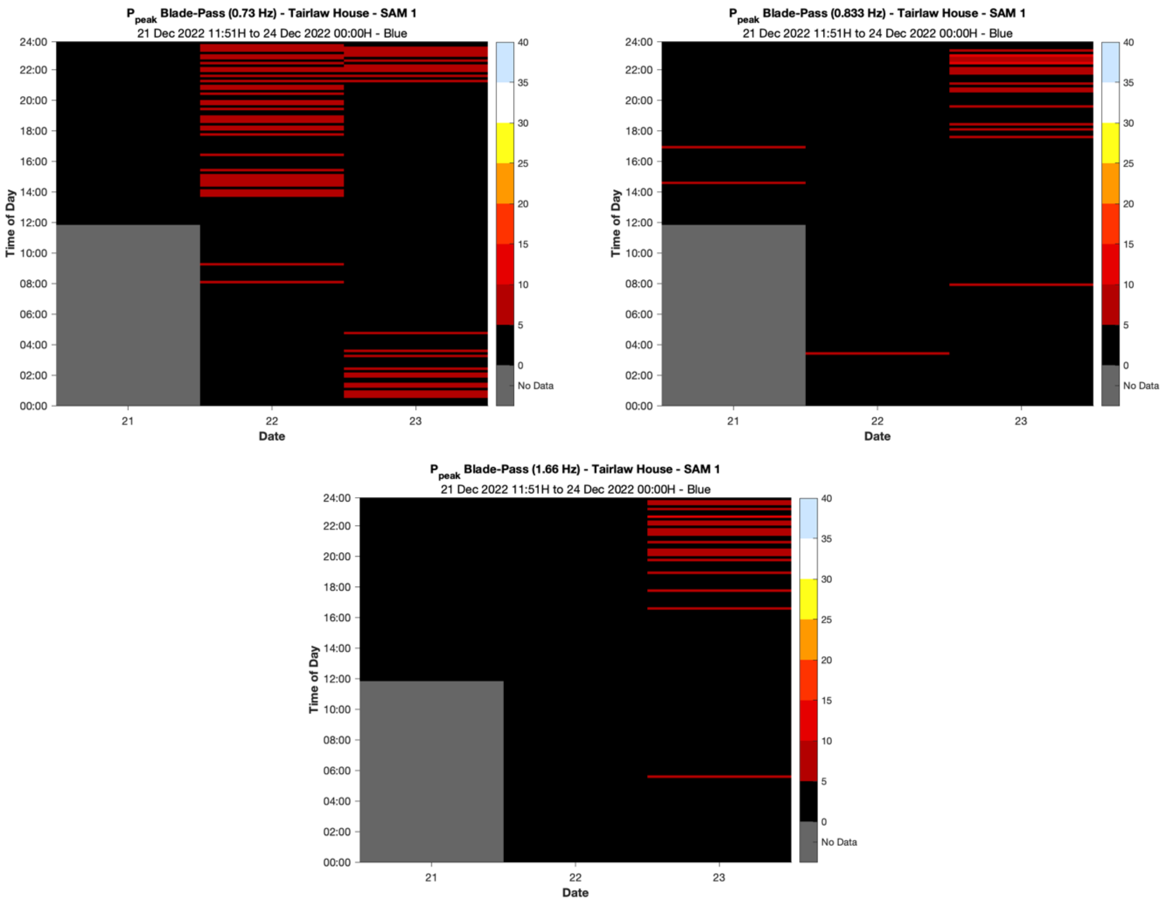

Figure 27: Time-of-day plots for Tairlaw House on 28 November 2022 for the 0.73-hertz (top-left), 0.833-hertz (top-right), and 1.66-hertz (bottom) harmonic series.

Glenhead

104. Analysis of the fundamental-frequency histogram (see **Figure 10**) for the period showed only a 1-hertz harmonic series in the range of 0.5 to 2 Hz.

105. The following figure shows harmonic analyses (top) and sonograms (bottom) from the Blue microphone (left) and Red microphone (right). There are two major harmonic series with fundamental frequencies at 1 Hz and 20 Hz. These are shown as red dots, and green triangles, respectively, in the upper plots and as horizontal lines in the lower plots.

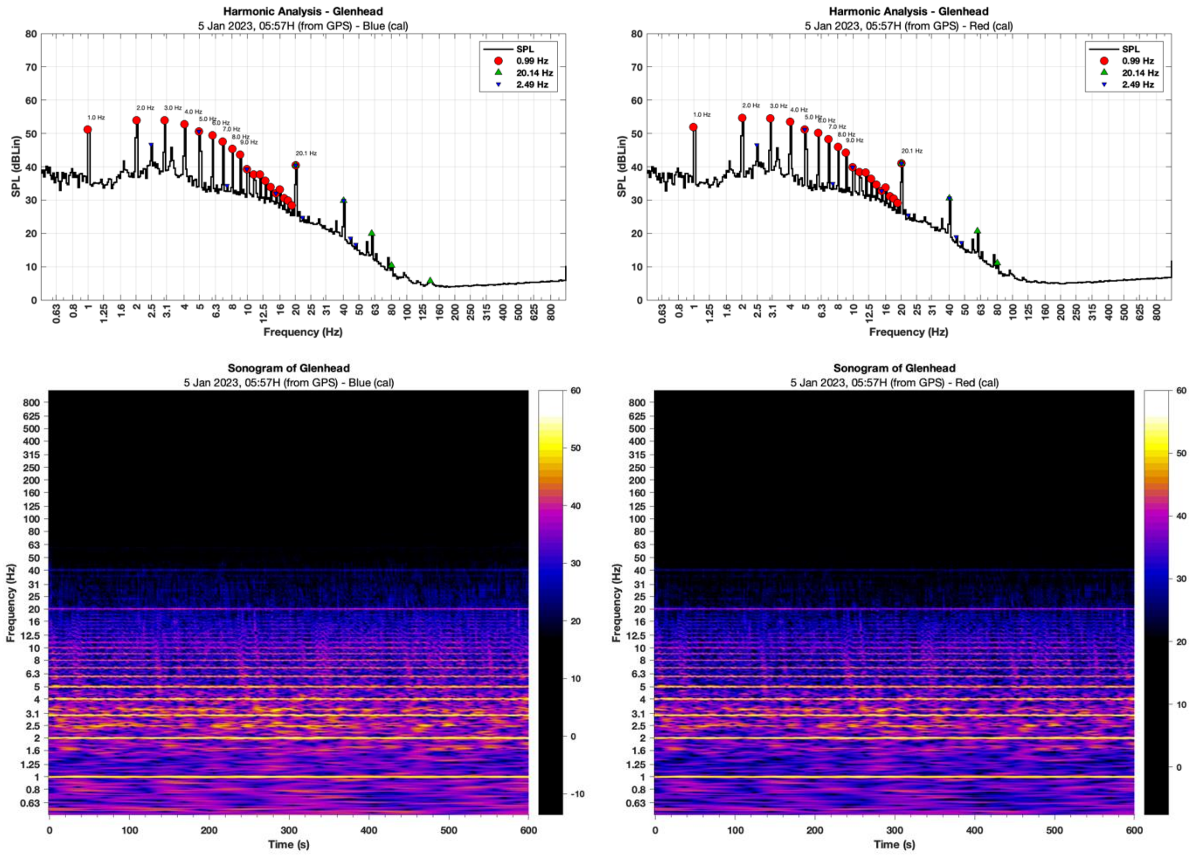

Figure 28: Harmonic analyses (top) and sonograms (bottom) for Glenhead at 06:00H, 5 January 2023. Blue microphone (left) and Red microphone (right).

106. Time-of-day plots of peak harmonic prominence are shown in the following figure for the 0.833-, 1- and 20-hertz harmonic series over the duration of the recording period (Blue microphone only).

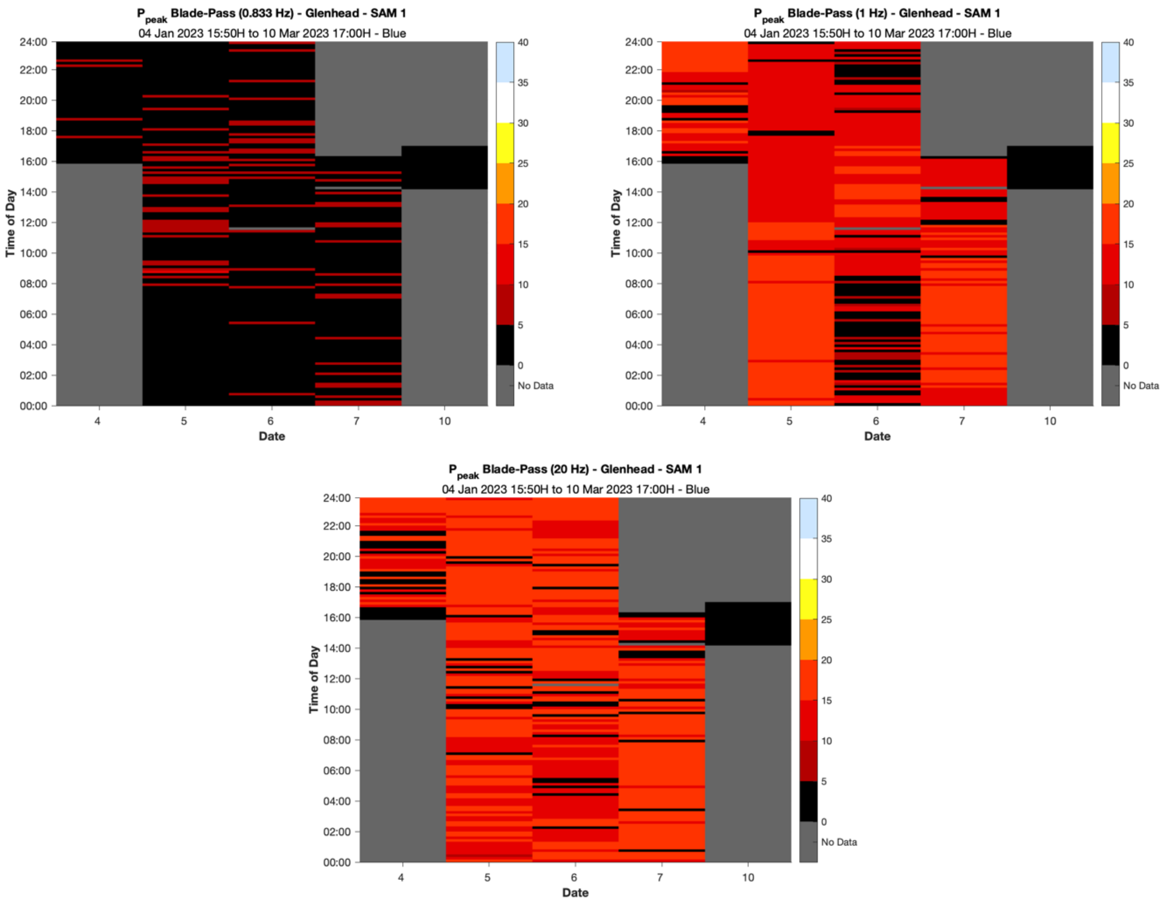

Figure 29: Time-of-day plots for Glenhead from 4 to 7 January, and 10 March, 2023 for the 0.833-hertz (top-left), 1-hertz (top-right), and 20-hertz (bottom) harmonic series.

Glengennet

107. Analysis of the fundamental-frequency histogram (see **Figure 10**) for this (brief) period showed a 1-hertz harmonic series in the range of 0.5 to 2 Hz as well as 1.87, 1.9 and 1.94 Hz.

108. The following figure shows harmonic analyses (top) and sonograms (bottom) from the Blue microphone (left) and Red microphone (right). There are two major harmonic series with fundamental frequencies at 1 Hz and 20 Hz. These are shown as red dots, and green triangles, respectively, in the upper plots and as horizontal lines in the lower plots.

109. Impulsive noise can also be seen in the sonograms (bottom) as bright, vertical lines. These are very likely due to human activities within the dwelling, as this is a working farm.

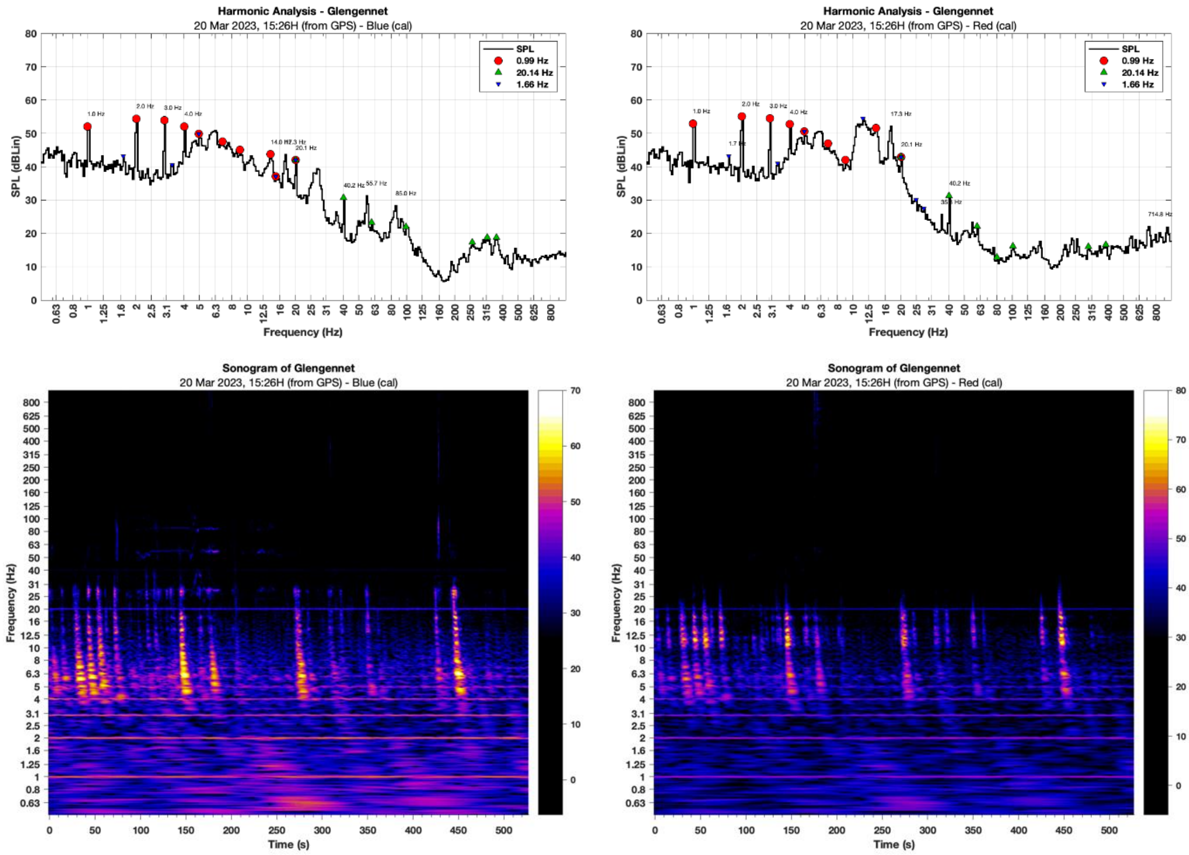

Figure 30: Harmonic analyses (top) and sonograms (bottom) for Glengennet at 15:30H, 20 March 2023. Blue microphone (left) and Red microphone (right).

110. Time-of-day plots of peak harmonic prominence are shown in the following figure for the 1- and 20-hertz harmonic series over the duration of the recording period (Blue microphone only).

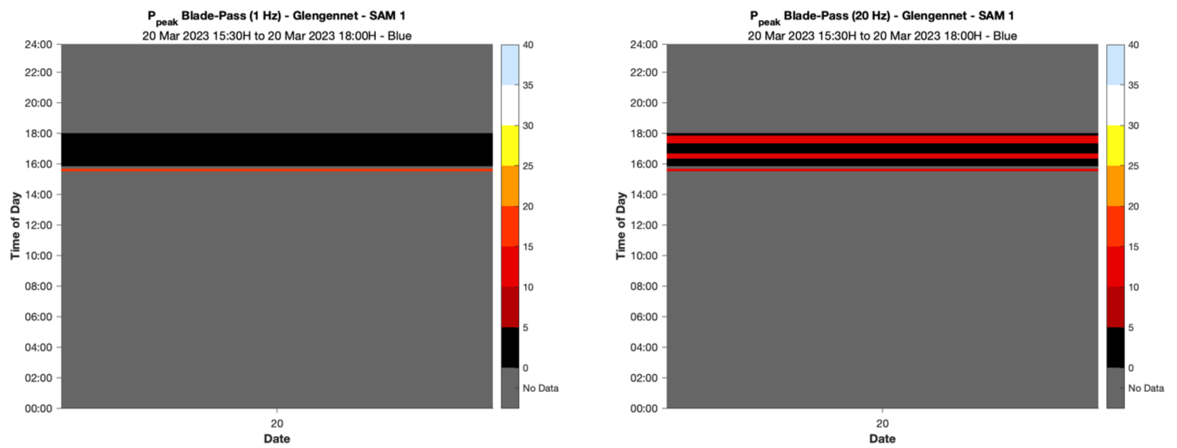

Figure 31: Time-of-day plots for Glenhead on 20 March, 2023 for the 1-hertz (left) and 20-hertz (right) harmonic series.

Glenapp Castle

111. Analysis of the fundamental-frequency histogram (see **Figure 10**) for the period showed no significant harmonic series in the range of 0.5 to 2 Hz.

112. The following figure shows harmonic analyses (top) and sonograms (bottom) from the Blue microphone (left) and Red microphone (right). Both show wind noise as the dominant features (high values, top, and bright colours, bottom) and some tonal sound of technological origin near 16 Hz (bottom right) and above 40 Hz (bottom left).

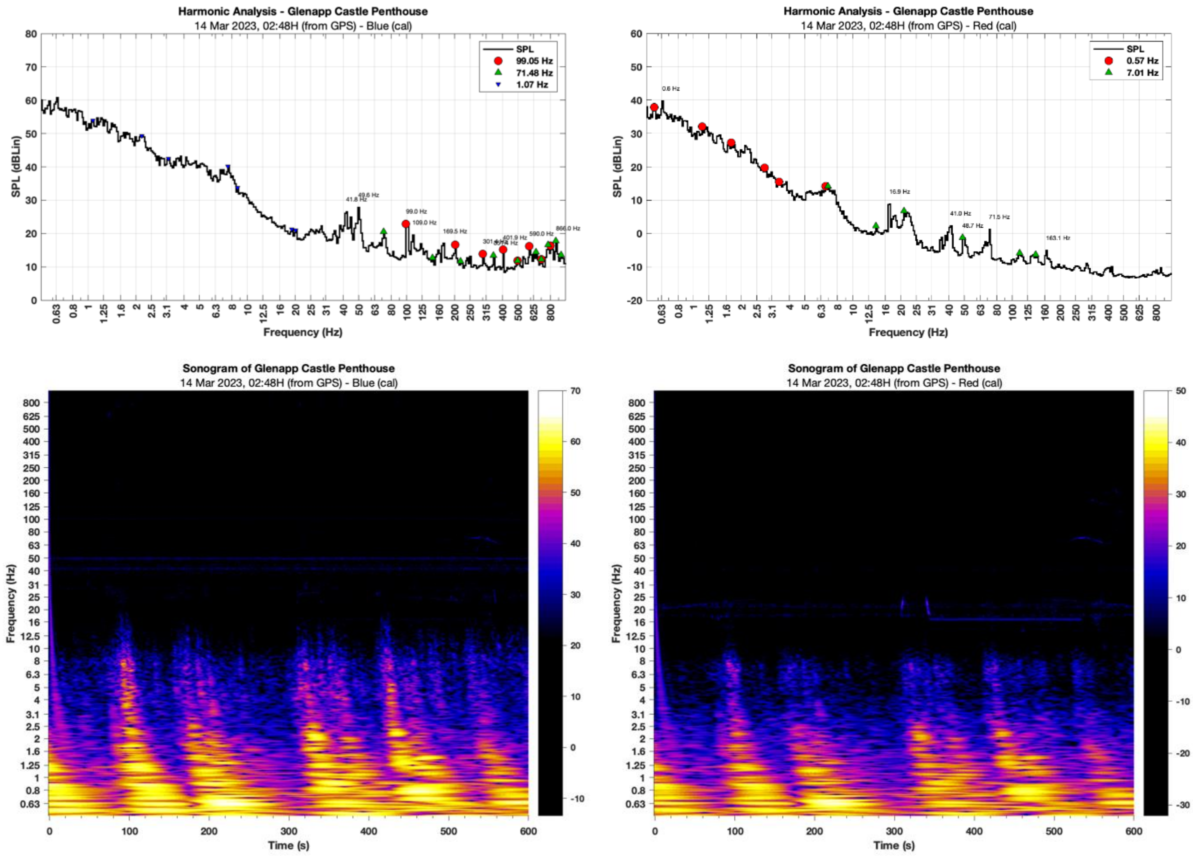

Figure 32: Harmonic analyses (top) and sonograms (bottom) for Glenapp Castle at 02:50H, 14 March 2023. Blue microphone (left) and Red microphone (right).

Barnfield

113. The following figure shows harmonic analyses (top) and sonograms (bottom) from the Blue microphone (left) and Red microphone (right). The Blue microphone (left) shows wind noise as the dominant feature (high values, top, and bright colours, bottom) and some tonal sound of technological origin near 16 Hz (bottom right) and above 40 Hz (bottom left). The Red microphone (right) shows what is likely human speech (top-right quadrant of bottom-right plot), as well as a 1-hertz and a 20-hertz harmonic series. These show as red dots and green triangles, respectively, in the top plot.

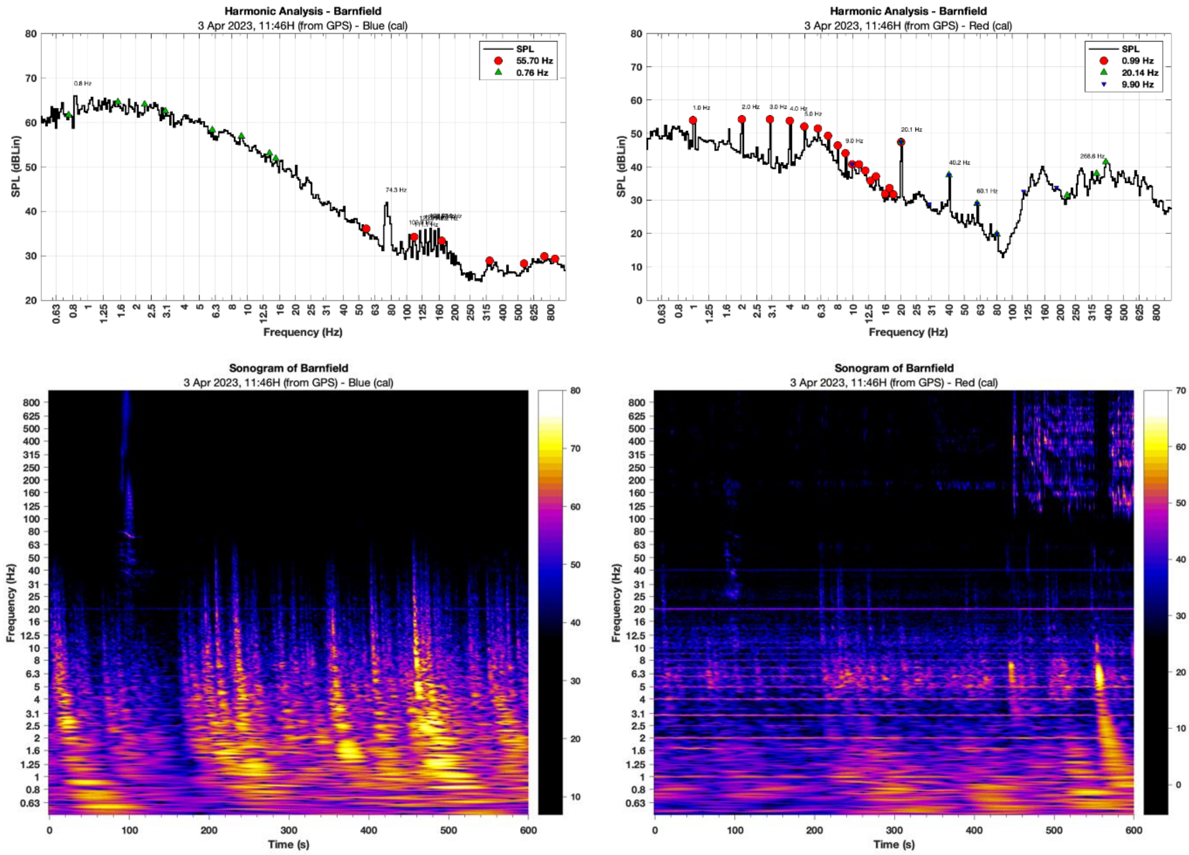

Figure 33: Harmonic analyses (top) and sonograms (bottom) for Barnfield at 11:50H, 3 April 2023. Blue microphone (left) and Red microphone (right).

114. Time-of-day plots of peak harmonic prominence are shown in the following figure for the 1- and 20-hertz harmonic series over the duration of the recording period (Red microphone only).

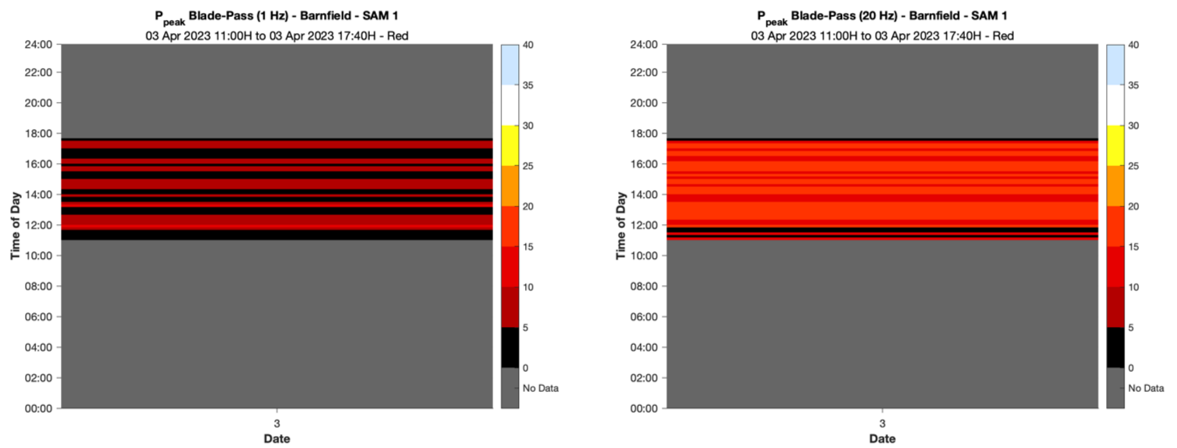

Figure 34: Time-of-day plots for Barnfield on 3 April 2023 for the 1-hertz (left), and 20-hertz (right) harmonic series.

High Tralorg

115. The following figure shows harmonic analyses (top) and sonograms (bottom) from the Blue microphone (left) and Red microphone (right). Both show mainly wind noise (high values, top, and bright colours, bottom) and a car, train or plane, at the end of the recording seen as descending lines (bottom) and peaks above (top).

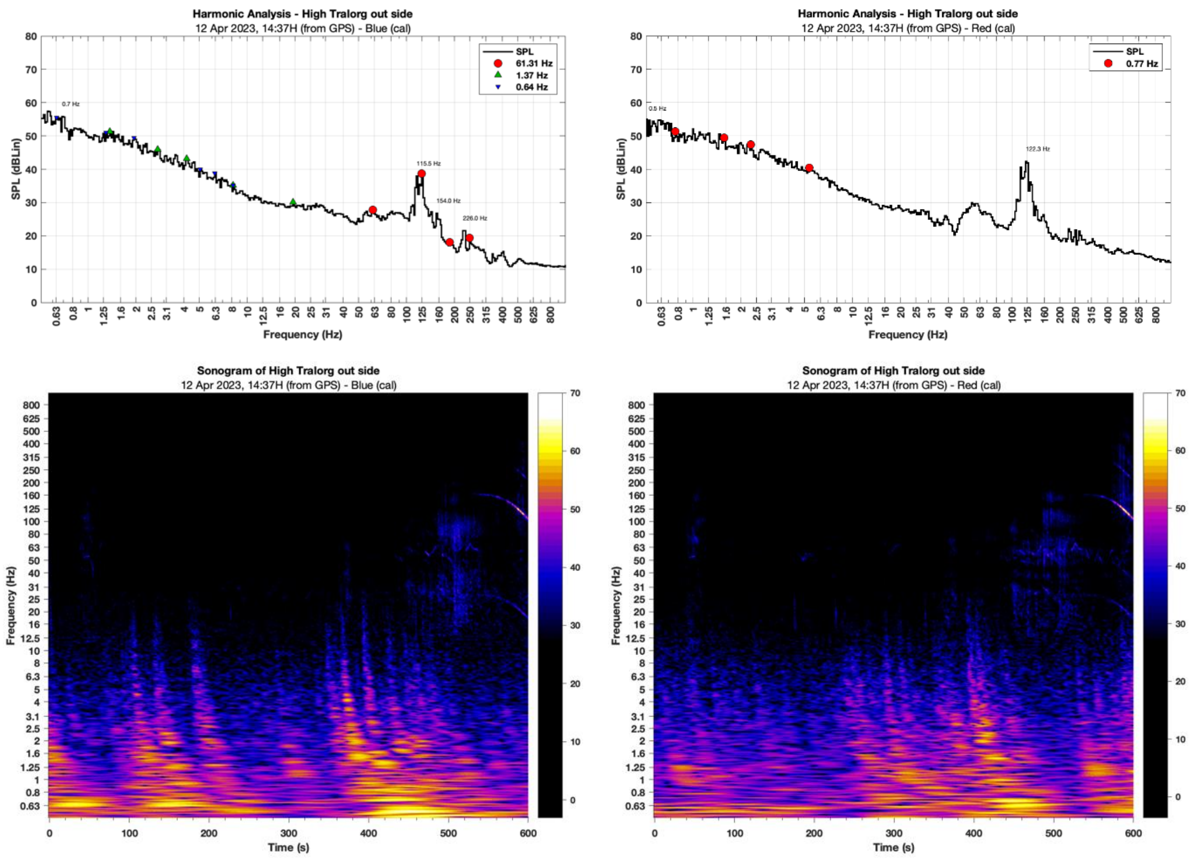

Figure 35: Harmonic analyses (top) and sonograms (bottom) for Barnfield at 11:50H, 3 April 2023. Blue microphone (left) and Red microphone (right).

VII. Wind Turbines

116. A wind turbine that is asynchronous does not directly change rotor speed with wind speed. Below their minimum windspeed of operation, they cannot operate and may be stationary or rotating at a lower speed (and lower BPF). More modern models will operate at an increasing rotor speed above this minimum windspeed until they reach their maximum rotor speed, which they will maintain up until their maximum operating windspeed.

117. The BPFs of wind turbine models can usually be inferred from manufacturers' specifications. Video recordings can be used to determine the actual BPF at a given time, which might vary up to the maximum rotor speed.

118. The following table shows manufacturers' data for the wind turbine models of the WPPs in the region of Barr and Straiton. From the figures, it is possible to calculate or measure the BPF by three methods (All are shown in the following table.),

a. using blade-tip speed and rotor diameter (BPF),

b. using maximum rotational speed and rotor diameter (maximum BPF),

c. using recorded video to count blade passes and video frames (measured BPF).

119. The following table summarises measurements of BPFs made by video recordings. These values could be much less than the BPFs as it is not certain that the turbines were at maximum rotational speeds, nor even generating power.

Table 3: Measured blade-pass frequencies from video recordings.

Location	BPF (date taken)	BPF	Max BPF
Tralorg	0.5–0.53 Hz (12 Apr 23)	0.95 Hz	0.95 Hz
Assel Valley	0.54-0.62 Hz (12 Apr 23)	0.92 Hz	0.92 Hz
Maclachrieston	0.82 Hz (12 Apr 23)		
Dersalloch	0.75–0.8 Hz (12 Apr 23)	0.95 Hz	0.95 Hz
Hadyard Hill	0.82–0.87 Hz (3 Apr 23)	0.85 Hz	0.85 Hz

F. DISCUSSION

Harmonic Series

120. WTAS is a series of pulses that occur at the blade-pass frequency. When WTAS is present from many turbines, generally one turbine is dominant with the pulses from other turbines being much smaller. It is possible, however, that more than one turbine shows distinctly separate pulses. When this happens, the harmonic series will have double or treble the fundamental frequency. That is, the BPF of two turbines might be 0.84 Hz but, between them, twice as many pulses are produced per second, leading to a 1.66-hertz harmonic series.

121. The following table summarises the harmonic series identified at each recording location and the likely source of the WTAS. Where a doubling of the BPF occurs, the correct BPF is shown in brackets.

Table 4: Harmonic series identified in recordings from various locations.

Location	Main Harmonic Series	Also Seen	Likely WPP
Knockskae	1 Hz, 20 Hz		Unknown

Knockskae Cottage	1.87 (0.94) Hz, 20 Hz	1.66 (0.83) Hz, 0.83 Hz, 1 Hz	Dersalloch
Glenalla Farm	1.87 (0.94) Hz	2 (1) Hz, 20 Hz	Tralorg, Dersalloch
Little Garroch	1.87 (0.94) Hz	1 Hz, 20 Hz	Dersalloch
Tairlaw House	0.73 Hz, 0.83 Hz	1.66 (0.83) Hz	Dersalloch
Glenhead	1 Hz, 20 Hz	0.83 Hz	Unknown, Dersalloch
Glengennet	1 Hz, 20 Hz	1.87 (0.94) Hz	Unknown, Tralorg
Glenapp Castle	None		
Barnfield	1 Hz, 20 Hz		Unknown
High Tralorg	None		

122. Combining the results of the above table with that of the time-of-day plots, the following statements can be made.

a. Knockskae Cottage

i. Regularly subjected to WTAS at up to 15 dB above the background. Most likely from the Dersalloch WPP.

ii. Subjected to WTAS at 5–10 dB above the background. From an unknown WPP with a BPF at or above 1 Hz.

iii. Almost continuously subjected to a 20-hertz tone at 5–20 dB above the background. Of unknown origin.

b. Glenalla Farm

i. Subjected to WTAS at up to 10 dB above the background. Most likely from the Tralorg and/or Dersalloch WPPs.

ii. Subjected to WTAS at 10–15 dB above the background. From an unknown WPP with a BPF at or above 1 Hz.

iii. Subjected to a 20-hertz tone at 5–15 dB above the background. From an unknown source.

c. Little Garroch

i. Regularly subjected to WTAS at up to 15 dB above the background. From an unknown WPP with a BPF at or above 1 Hz.

ii. Almost continuously subjected to WTAS at 5–20 dB above the background. Most likely from the Tralorg and/or Dersalloch WPPs.

iii. Almost continuously subjected to a 20-hertz tone at 5–15 dB above the background. Of unknown origin.

d. Tairlaw House

   i. Sometimes subjected to WTAS at 5–15 dB above the background. Most likely from the Dersalloch WPP.

e. Glenhead

   i. Sometimes subjected to WTAS at 5–10 dB above background. Most likely from the Dersalloch WPP.

   ii. Can be continuously subjected to WTAS at 10–20 dB above background. From an unknown WPP with a BPF at or above 1 Hz.

   iii. Can be continuously subjected to a 20-hertz tone at 10–20 dB above the background. From an unknown source.

f. Glengennet

   i. Sometimes subjected to WTAS at 5–10 dB above background. Most likely from the Tralorg WPP.

   ii. Sometimes subjected to WTAS at 15-20 dB above background. From an unknown WPP with a BPF at or above 1 Hz.

   iii. Sometimes subjected to a 20-hertz tone at 5–15 dB above background. From an unknown source.

g. Glenapp Castle

   i. Was not subjected to any WTAS or other tonal noise during the recording period.

h. Barnfield

   i. Was subjected to WTAS at 5–15 dB above background. From an unknown WPP with a BPF at or above 1 Hz.

   ii. Can be continuously subjected to a 20-hertz tone at 10–20 dB above background. From an unknown source.

i. High Tralorg

   i. Insufficient length of recording to be significant.

123. In summary, many of the recording locations are already subjected to WTAS from one or more sources, some of which can be tentatively identified. Many are also subjected to a 20-hertz tone.

124. The source of the WTAS with a 1-hertz BPF was not identified. It is unlikely to be a frequency-doubled WTAS as no nearby WPPs operate at a BPF of 0.5 Hz. Other WPPs are unlikely to operate at this BPF for any length of time as part of normal operation.

G. CONCLUSIONS

125. High-resolution recordings of low-frequency sound and infrasound from several locations in the Barr/Straiton area, and subsequent analyses, indicate that the following locations are already subjected to WTAS from several WPPs: Knockskae Cottage, Glenalla Farm, Little Garroch, Glengennet, Tairlaw House, Glenhead, and Barnfield.

126. A further WTAS source, with a BPF at or above 1 Hz, affected Knockskae Cottage, Glenalla Farm, Little Garroch, Glengennet, Glenhead and Barnfield. Its source could not be identified.

127. All locations affected by this unknown source were also affected by a 20-hertz tone, also of unknown origin.

128. No sign of WTAS or a pervasive tone were identified High Tralorg or Glenapp Castle. In the former the recording period was too short to suggest that the absence was typical.