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Evaluation of wind turbine-related noise in western New York State

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Summary

This study was conducted at an installation of eighty-four 1.5-megawatt wind turbines in rural western New York. Meteorological and noise measurements were conducted during summer, autumn, and winter at residential properties near operating turbines, as well as at well-removed "background" locations. A community survey was conducted to evaluate resident satisfaction and self-reported health effects. Sound levels at most turbine locations exceeded those at the corresponding background locations by a significant margin. Overall resident satisfaction with living environment was generally positive, while opinions on wind turbines were mixed, and the rate of official noise complaints was similar to other wind developments in the USA.

1. Introduction

The goals of this study were to assess environmental noise levels in and around a modern operating New York wind power installation, and to study the perception, level of annoyance, and health impacts reported by nearby residents.

A large, recently-constructed wind turbine park in western New York State was selected, without the direct participation of the utility operator. The 126 MW facility located in Wyoming County, New York began operation in March 2009 and comprises eighty-four 1.5 MW General Electric model 1.5sle turbines spanning approximately 50 square km of rural farmland. Each turbine has a hub height of 80 m and a rotor diameter of 77 m. This turbine has a published (GE Wind, 2005) maximum sound power wind speed of 9 m/s at hub height, above which noise emission does not increase. According to the manufacturer, this is equivalent to a maximum noise emission wind speed of approximately 7 m/s at a standardized 10 m

height (with the manufacturer assuming a logarithmic wind profile and characteristic roughness of 0.03 m).

Extended noise monitoring was conducted at five receptor locations within the wind park, as well as at up to two locations removed from the wind park to provide comparison “no turbine” measurements. This monitoring was conducted over three separate campaigns (1: August 2011, 2: October 2011, and 3: February 2012), each consisting of four days of continuous monitoring. During the October campaign, questionnaires were administered to residents living within the wind park to assess the prevalence of annoyance associated with living in close proximity to wind turbines, and of self-reported health effects perceived to be related to the wind turbines. These surveys were modelled after similar applications in the existing literature related to wind farm noise impacts (Pedersen et. al. 2004, 2007, 2009). Short-term outdoor and indoor sound level measurements were also performed at each dwelling in which a questionnaire was administered. Statistical analyses were conducted to determine the nature of the association between the noise monitoring, short-term measurements, and questionnaire results.

2. Methods

2.1 Selection of noise monitoring locations

Five noise monitoring locations (“A” through “E”) were selected by identifying parcels of residential property near one or more wind turbines, but without a turbine or infrastructure on the property itself. The distances from monitoring location to nearest wind turbine ranged from 219 m to 663 m. The terrain surrounding the wind turbines is rural and used primarily for agriculture, with sparse stands of woods and small shrub growth on rolling hills.

Since background ambient noise monitoring could not be conducted with the turbines parked, two alternative locations were selected outside of the area. These “background” locations were selected with consideration for similar elevation, terrain, and proximity to roadways as the operational locations, with a minimum distance of 4.6 km from the nearest wind turbine. One background location was excluded and replaced after the first campaign due to excessive traffic noise exposure, and one location was excluded from the third campaign due to equipment malfunction. As such, the second campaign includes data from two background locations, while the first and third campaigns include one background location each.

To encourage participation, each resident that allowed long-term noise monitoring on their property was given a $50 gift card at the conclusion of the study.

2.2 Noise measurement procedures

Procedures for extended noise logging at the receptor locations were guided by the International Energy Agency Wind Agreement (“IEA Wind”) recommended practice for noise receptor immission measurement from operating wind turbines (Ljunggren 1997).

At each location, broadband sound pressure levels and 1/3-octave band spectra were collected in 10-minute periods using a Type 1 sound level meter with tripod-mounted microphone (to represent a standing listener) and hydrophobically-treated 175 mm diameter foam windscreen. The large windscreen was chosen to reduce wind-induced “self-noise” at high wind speeds and at low frequencies; published

spectra for insertion loss and wind tunnel tested self-noise for this windscreen at various wind speeds (G.F. Hessler et. al. 2008, ACO Pacific 2008) were incorporated into the data analysis. Because the published self-noise is based on wind tunnel testing, these data likely represent a lower bound on realistic values in gusty or turbulent wind.

Average wind speed, direction, and other weather conditions were logged on concurrent 10 minute intervals during the noise monitoring. A 10 m tall wind mast was deployed for this purpose on the same property as Location D. Using a hand-held anemometer, wind speed measurements at microphone height were conducted intermittently at all monitoring locations for comparison with the wind speeds measured at the wind mast.

2.3 Summary of conditions at monitoring locations

Table 1 summarizes the monitoring locations in terms of the distances and headings to the closest three turbines.

Table 1 - Noise receptor measurement locations.

Location	Distances to 3 Nearest Turbines (m)	Headings to 3 Nearest Turbines
A	663 / 813 / 856	NW / N / WNW
B	305 / 506 / 770	WNW / NW / SSE
C	317 / 345 / 449	NNE / SSE / SSW
D	219 / 427 / 666	NW / N / W
E	421 / 549 / 789	WNW / NNW / W
Background	> 4600	

The weather conditions varied substantially both within and among the campaigns. The August campaign had temperatures ranging from 12°C to 26°C and 10-minute average 10 m wind speeds ranging from 0 to 7.6 m/s, with no significant precipitation. Wind speeds in October ranged from 0 to 9.4 m/s with temperatures ranging from 2°C to 19°C, with occasional periods of moderate to heavy rain. The third campaign exhibited the highest sustained wind speeds with averages of up to 12.1 m/s. Temperatures ranged from -13°C to 1°C with steady moderate snowfall occurring for approximately two days, leading to substantial ground cover at the conclusion of the period. In each campaign, wind direction was predominantly from the WNW to NNW when winds were consistent, precluding evaluation of upwind/downwind effects.

2.4 Noise data analysis

Analysis methods for the logged noise data were guided by the IEA Wind recommended practice for immission measurements (Ljunggren 1997). In this practice, A-weighted L_{eq} values (and optionally spectral values) are plotted against the concurrent wind speeds, with a best-fit line then applied to the resulting data scatter. In this case, direct subtraction of background values (to determine a turbine-only noise level) was not attempted, since direct background measurement at each distinct receptor location was not possible. Values from the remote background sites are therefore presented as a basis for comparison.

Where loud noise interference (such as thunder, gunshot, or immediate farm activity) could be positively identified through recorded audio samples, these data points were censored from further analysis. Unweighted 1/3-octave band spectral L_{eq} values for

each period were then corrected for windscreen attenuation (G.F. Hessler et. al. 2008, ACO Pacific 2008) and summed into three wide bands: an unweighted L_{eq} including 6.3 Hz through 16 Hz (representing an infrasound range), an unweighted L_{eq} including 20 Hz through 250 Hz (representing a low-frequency range), and an A-weighted LA_{eq} including 6.3 Hz through 3.15 kHz (a broadband A-weighted range). The frequency bands beyond 3.15 kHz were truncated from the LA_{eq} frequency range to avoid substantial insect noise contribution during the summer campaign; the exclusion did not substantially affect the results in the remaining campaigns, when insect noise was absent.

For each data set, a best-fit line was plotted against the L_{eq} versus wind speed scatter. A sample set is presented in Fig. 1, for the A-weighted data set from Location D, Campaign 1. These data are plotted along with the approximate wind-induced self-noise at the microphone, based on a logarithmic fit to the data of G.F. Hessler, et. al. (2008) for the specific windscreen in use. Since self-noise is a function of wind speed at the microphone height (2.4 m), these microphone-height wind speed values are estimated from the measured wind speed at 10 m using a logarithmic wind speed conversion (Ljunggren 1997), with the characteristic roughness taken as 0.05 m for farmland. Ground-level wind speed measurements were made periodically during the study, and these generally fell near or below the value extrapolated from the wind mast data, indicating a conservative estimate.

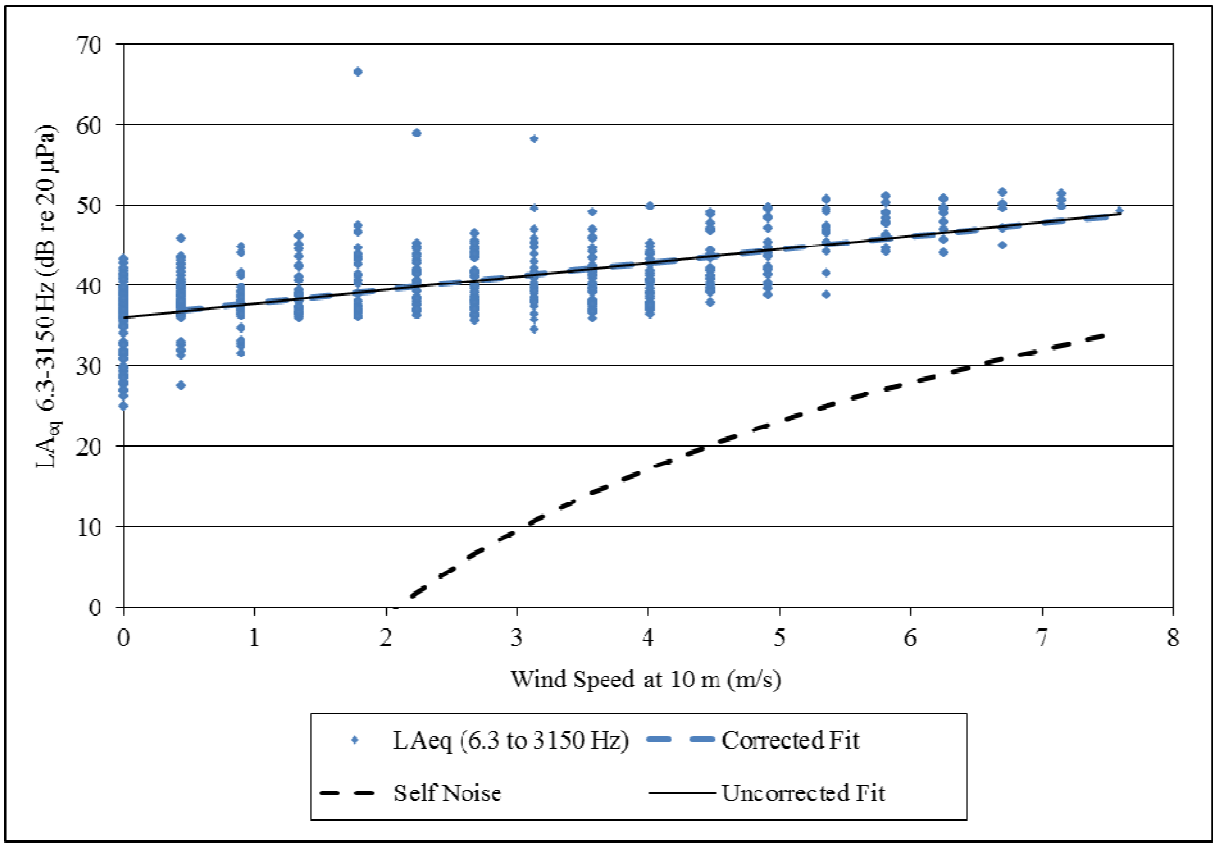

Fig. 1 - Location D, A-weighted data from Campaign 1, with best-fit line and best-fit line corrected for wind-induced self-noise.

Because the true wind profile may vary from the logarithmic approximation used, because local wind speed may vary with the significant geographic distance from the single wind mast, and because the published self-noise values were obtained for

steady airflow in a wind tunnel, the resulting self-noise values are approximate and should be considered a lower bound. Fig. 1 also contains a “corrected fit” curve, which is the best-fit line corrected with a decibel subtraction of the corresponding self-noise values.

2.5 Community survey methods

During the second (autumn) campaign, a community survey was developed and administered to 62 individuals living and working in the 28 square miles encompassing the selected wind project. The survey was administered in person by two field personnel during daytime hours, with visits in October and November 2011. The survey instrument included objective questions centered on annoyance issues and self-reported health effects, and was primarily adapted from that developed by Pedersen et. al. (2004). Residents were provided a brief summary of the project along with project contact information, and participation was voluntary. Each session lasted approximately 20 minutes, with a few instances lasting up to 40 minutes. Institutional Review Board (IRB) review of the survey protocol and instrument was sought, and an exemption from IRB oversight was granted.

In conjunction with the in-person survey administration, outdoor meteorological measurements and 10-minute noise measurements within and outside each home were collected for use in later statistical analysis.

3. Results

This presentation summarizes only selected results from the noise monitoring; full detailed results may be found in the final public project report (NYSERDA 2013).

Figure 2 presents the best-fit line to the A-weighted data at Loc. D, Campaign 1, compared with data from a background location (Background 1) during the same campaign. Both fit lines have been corrected for the approximate self-noise; as with most of the A-weighted data, this self-noise correction was not consequential except at the very highest wind speeds.

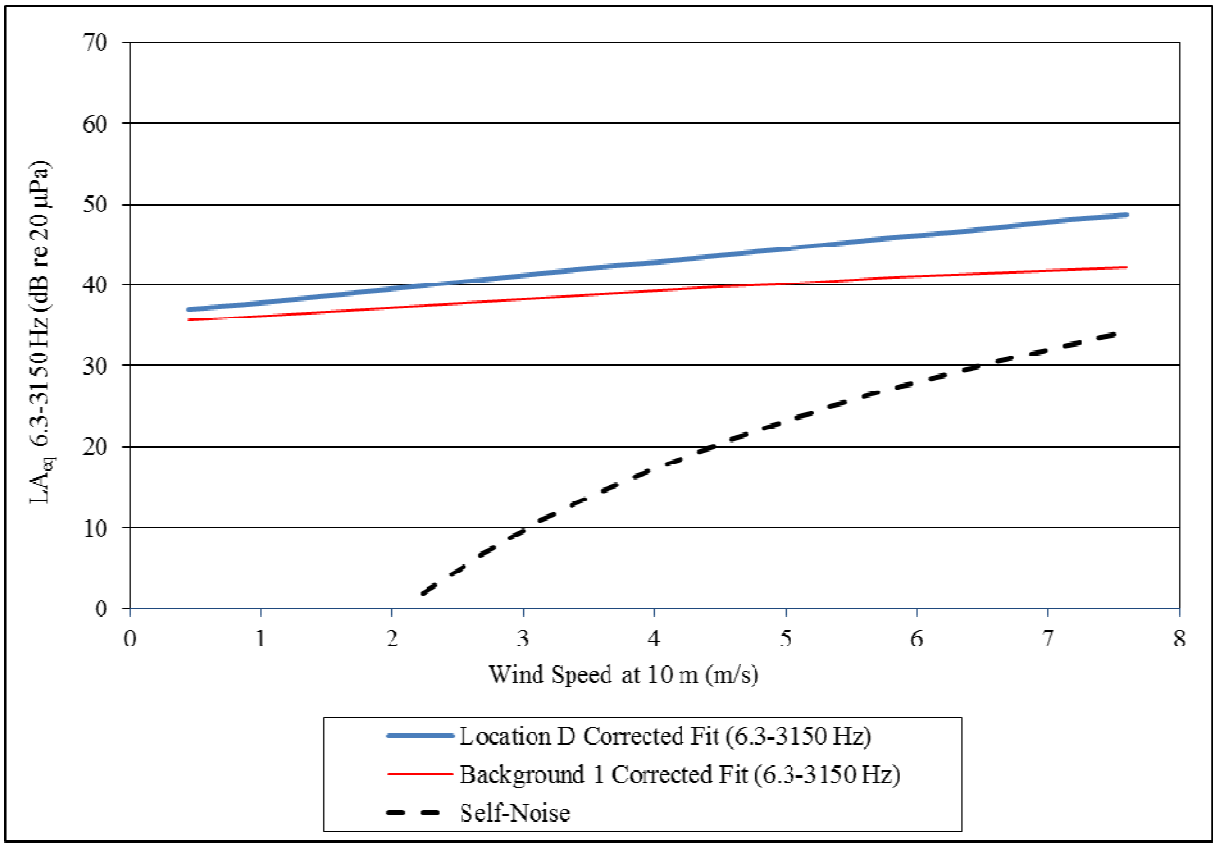

Fig. 2 - Self-noise corrected best-fit line for Location D, A-weighted data from Campaign 1, with corrected best-fit line for Background 1

Figures 3 and 4 present data from the same location and period as Fig. 2, but for the selected unweighted infrasound range (Fig. 3) and the selected unweighted low-frequency range (Fig. 4). At these lower frequencies, the self-noise was significant enough at high wind speeds to substantially modify the fit line for the Background 1 data, indicating that much of the measured value may be due to wind-induced noise and not actual sound pressure. This illustrates the difficulty in directly measuring low-level infrasound and low-frequency sound in a windy environment.

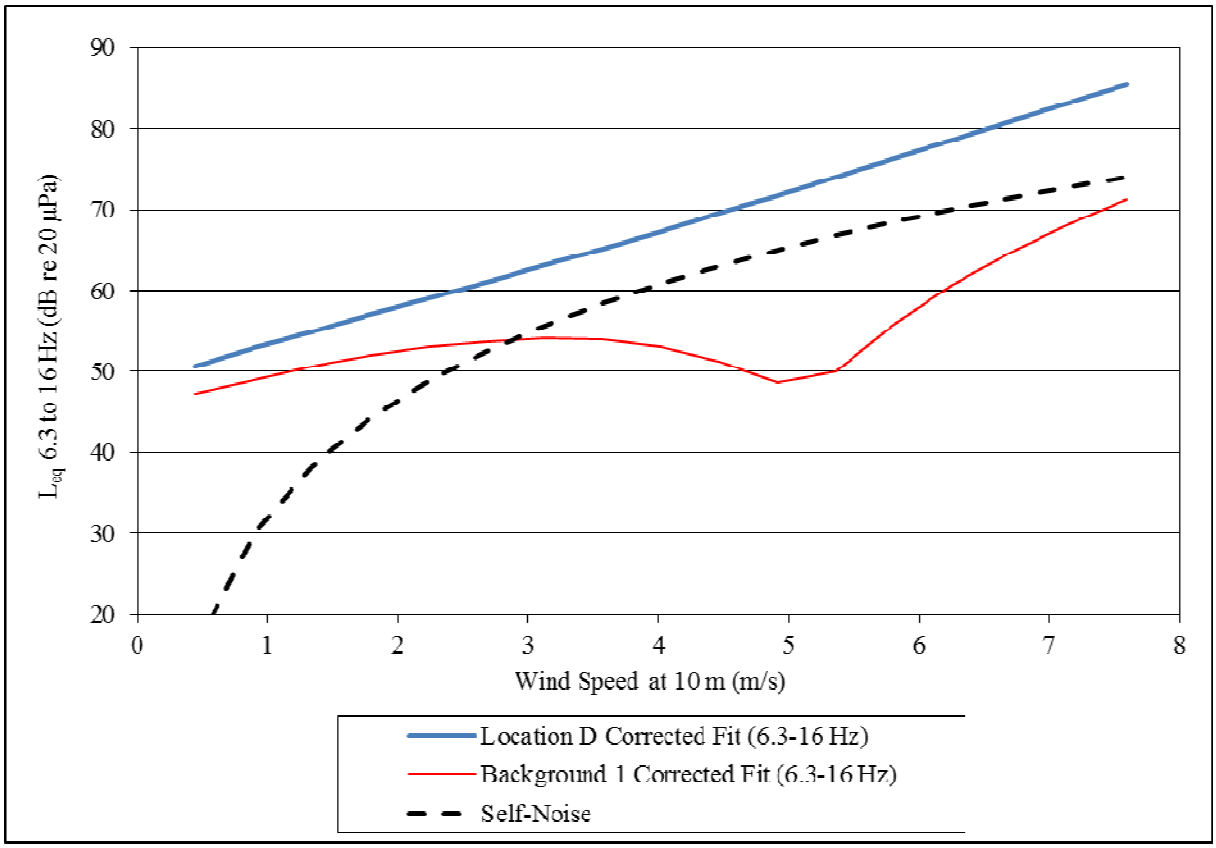

Fig.3 - Self-noise corrected best-fit line for Location D, infrasound data from Campaign 1, with corrected best-fit line for Background 1

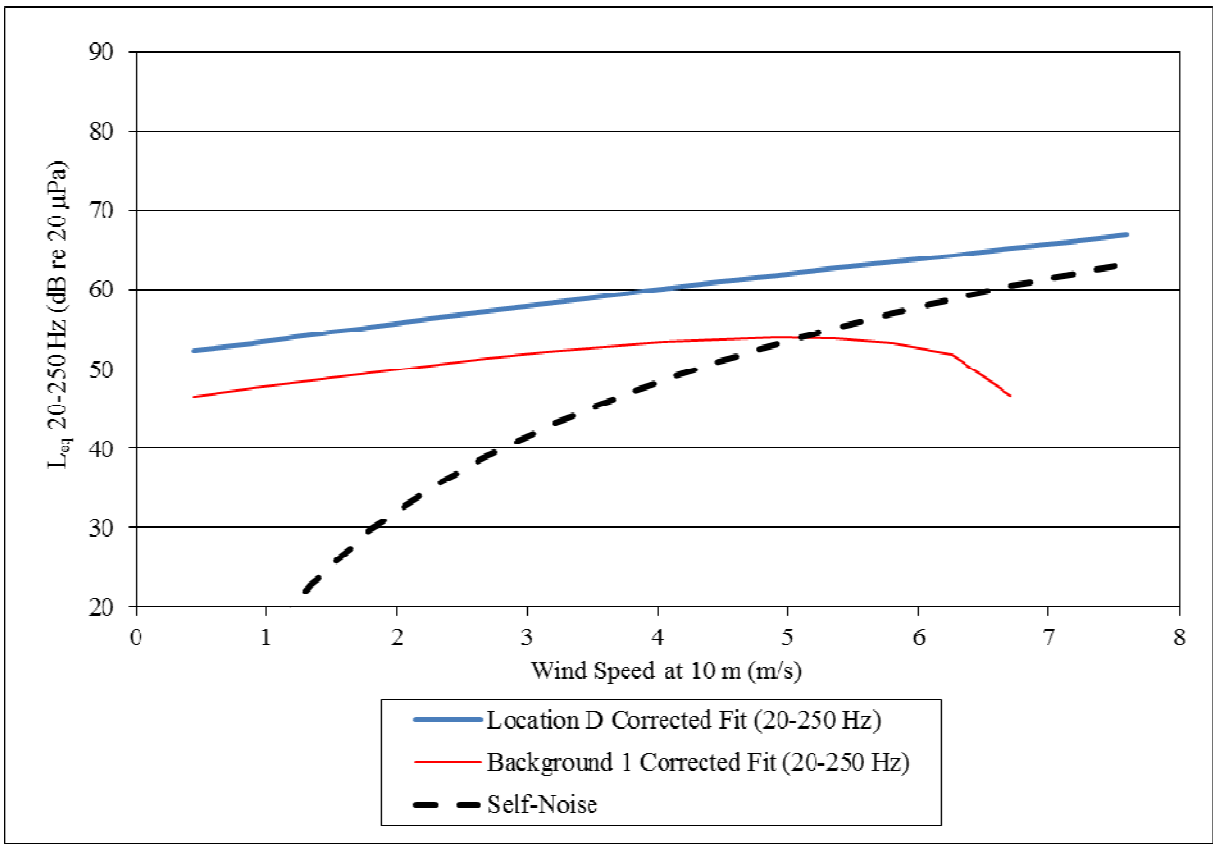

Fig.4 - Self-noise corrected best-fit line for Location D, low-frequency data from Campaign 1, with corrected best-fit line for Background 1

Figures 5, 6, and 7 summarize the study results across all three campaigns for the selected A-weighted, low frequency, and infrasound ranges respectively. These figures illustrate the best-fit values taken at a wind speed of 7 m/s at 10 m, which is the published maximum sound output speed for the turbine (see Sec. 1). In these figures, background location data and the self-noise estimate are plotted for comparison, but have not been directly subtracted from the turbine location data.

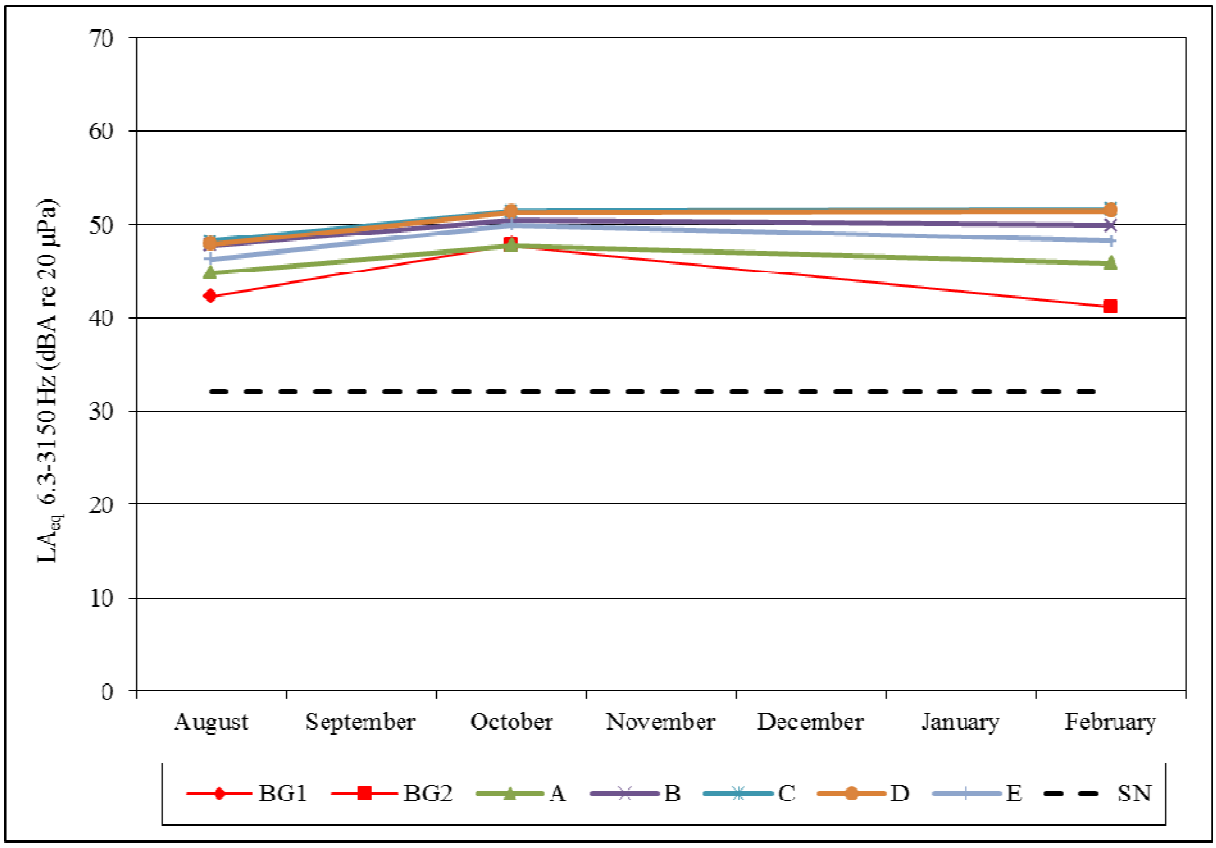

Fig. 5 - Best-fit SPL at 7 m/s wind at 10 m, A-weighted LA_{eq} (6.3 Hz–3150 Hz). "BG#" = Background, "A"-"E" = Measurement locations, "SN" = Self-noise.

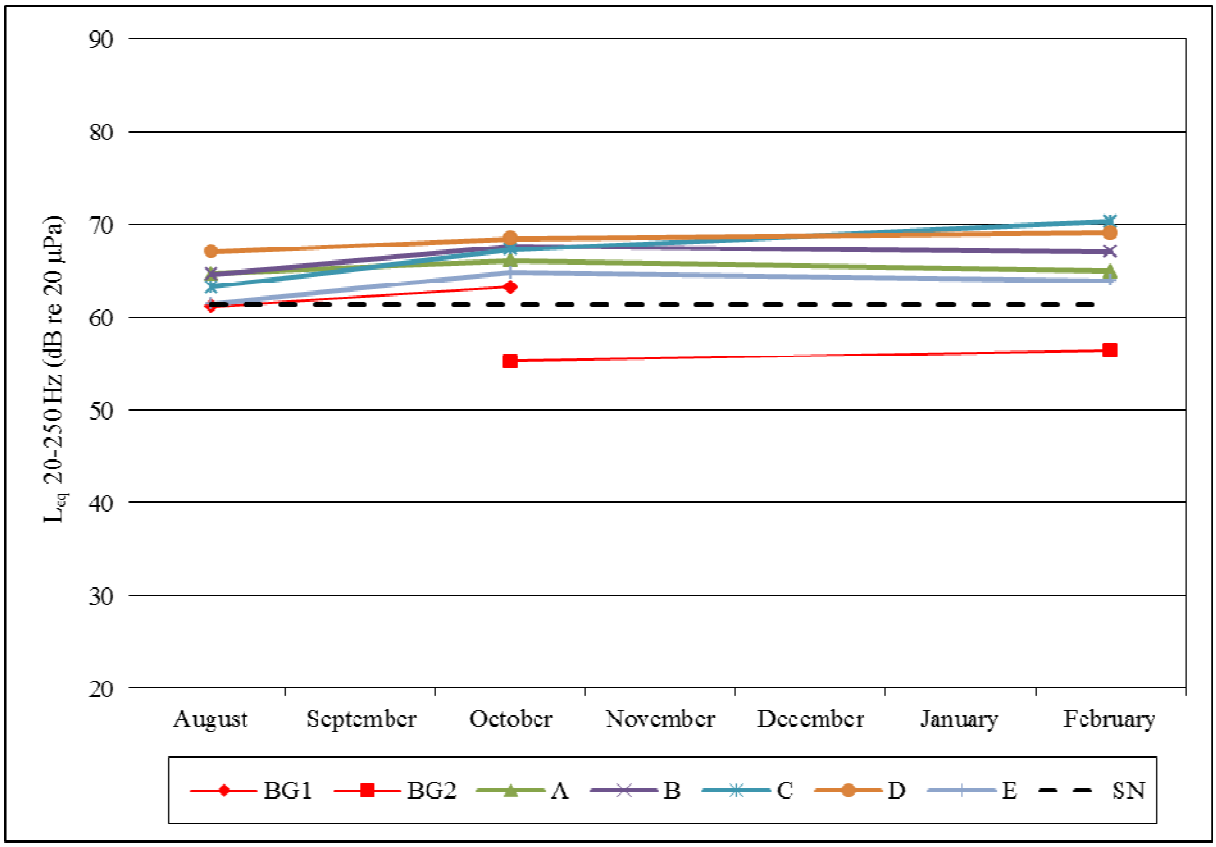

Fig. 6 - Best-fit SPL at 7 m/s wind at 10 m, unweighted L_{eq} (20 Hz–250 Hz). "BG#" = Background, "A"-"E" = Measurement locations, "SN" = Self-noise.

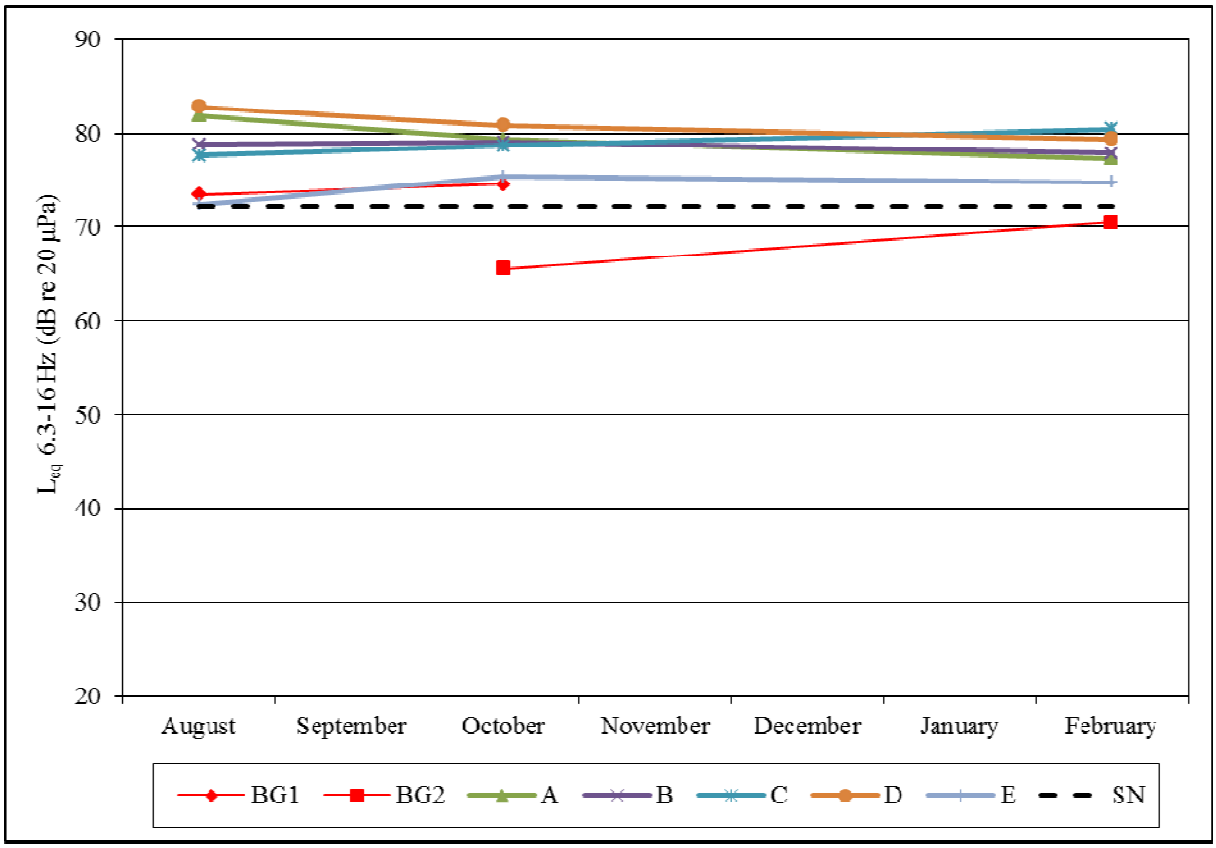

Fig. 7 - Best-fit SPL at 7 m/s wind at 10 m, unweighted L_{eq} (6.3 Hz–16 Hz). "BG#" = Background, "A"-"E" = Measurement locations, "SN" = Self-noise.

3.1 Background noise comparison

Prior to construction of the project, background noise monitoring was conducted by others as part of an environmental impact study (D.M. Hessler 2007). These December 2007 measurements occurred across six locations and fourteen days, yielding the fourth-order best fit of LA_{90} noise level to wind speed published in the prior study. Figure 8 compares the results of this pre-development study to a similar fit of the background location LA90 values from the comparable winter campaign in the present study. The values are similar at wind speeds of up to 5 m/s, beyond which the current values are up to 5 dBA lower. This could possibly be attributed to the prior study combining six locations into one data set, as compared with a single location in the present data; the former values may be sensitive to one or two locations with elevated wind noise exposure in high winds.

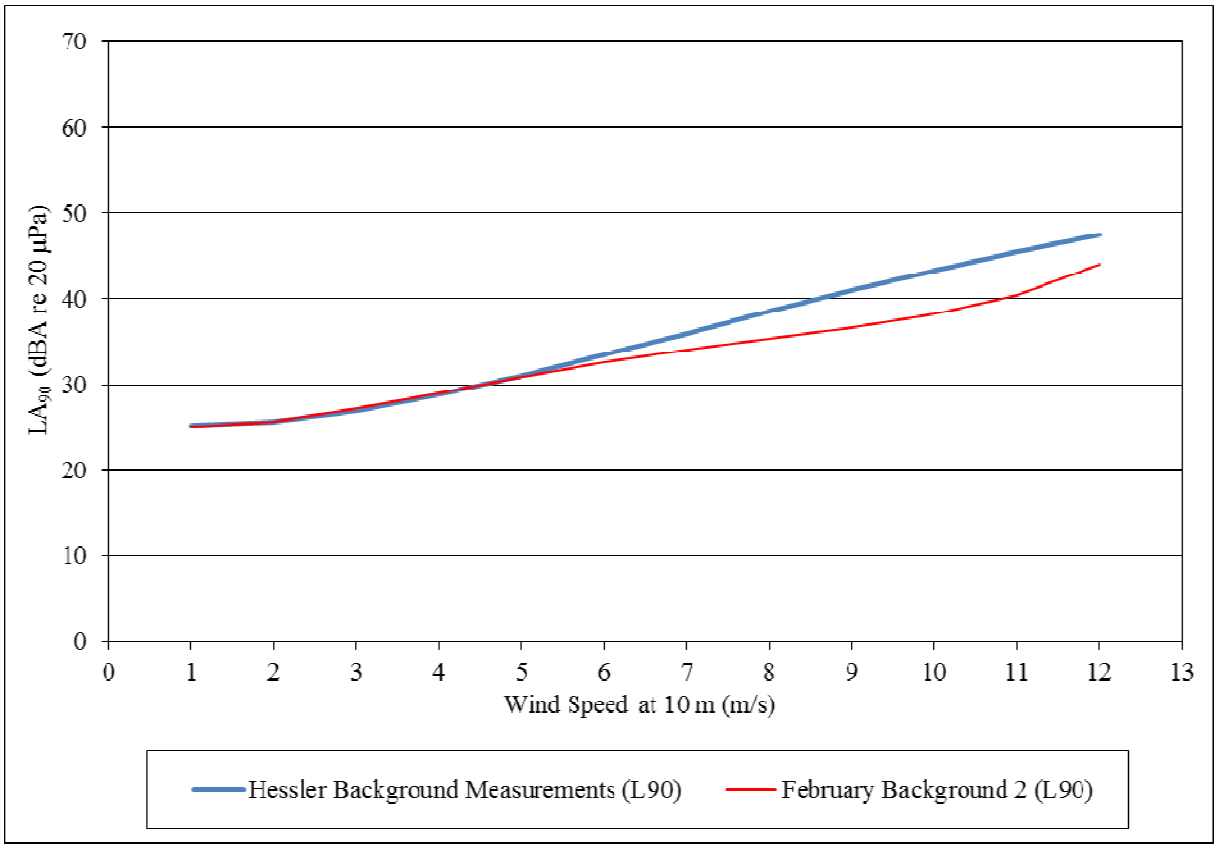

Fig. 8 - December 2007 pre-development study background LA_{90} (D.M. Hessler 2007) compared with Feb. 2012 "Background 2" LA_{90}.

3.5 Community survey

This presentation summarizes only selected results from the community survey portion of the project; full detailed results and statistical analysis may be found in the final public project report (NYSERDA 2013).

Table 2 summarizes selected demographic information on the responses to the community survey, while selected survey responses related to annoyance are presented in Table 3. The large majority of participants (90%) were either very satisfied or satisfied with their living environment, while general opinions on wind turbines were mixed (44% positive, 34% negative). Some level of annoyance by

wind turbine noise outside was reported by 44% of respondents, with 32% reporting some level of annoyance with turbine noise indoors.

Six individuals representing five households (out of 60 households visited) indicated that they had issued at least one formal noise complaint in response to wind turbine noise. This complaint rate of 8.3% by household is similar to the 2% to 7% reported by G.F. Hessler et. al. (2011) in a survey of five similarly-sized U.S. wind projects.

All respondents were receiving a substantial property tax reduction as a result of the turbine project, along with other benefits including free garbage removal. Those individuals that additionally reported a direct arrangement with the wind developer were overall more likely to be satisfied with their living environment, but not necessarily less likely to be annoyed with wind turbine noise outside or inside their homes. This contrasts with the findings of Pedersen et. al. (2009) in the Netherlands, where study participants were less likely to be annoyed by wind turbine noise if they were receiving some economic benefit (direct or otherwise).

During the in-person survey administration, 10-minute noise measurements were taken both within and outside each home for use in later statistical analysis. Because these one-time measurements could not be controlled for wind speed and interfering activity at the time of measurement, however, their suitability as a controlled metric for representing wind turbine noise exposure was mixed, and there were no statistically significant ($p<0.05$) associations between these short measurements and the self-assessment survey responses. Using calculated models rather than measurements, prior studies (Pedersen et. al. 2004, 2007, 2009) have noted exposure-response relationships between annoyance and modelled wind turbine noise levels at residences. Although modelled sound levels do correlate reasonably well with turbine noise emission, individual measured data points at the receiver (as collected here) can vary significantly from the underlying trend (G.F. Hessler et. al. 2011, Forssén et. al. 2010).

Table 2 - Selected community survey demographic information (mean ± std. dev.)

Number of responses	62
Mean age	51 ± 15 years
Mean distance from residence to closest turbine	586 ± 179 m
Mean number of turbines visible from residence	19 ± 17 turbines
Moved in before turbines operational	53 (86%)

Table 3 - Selected community survey responses on annoyance (62 total).

Satisfaction with living environment		
Very satisfied	29 (47%)	90%
Satisfied	27 (44%)	
Neither satisfied nor dissatisfied	2 (3%)	
Not satisfied	3 (5%)	6%
Not at all satisfied	1 (2%)	
General opinion on wind turbines		
Very positive	6 (10%)	44%
Positive	21 (34%)	
Neither positive nor negative	13 (21%)	
Negative	10 (16%)	34%
Very negative	11 (18%)	
Opinion on turbines' impact on landscape		
Very positive	3 (5%)	18%
Positive	8 (13%)	
Neither positive nor negative	29 (47%)	
Negative	8 (13%)	35%
Very negative	14 (23%)	
Altered view outside		
Do not notice	36 (58%)	73%
Notice but not annoyed	9 (14%)	
Slightly annoyed	7 (11%)	
Rather annoyed	6 (10%)	27%
Very annoyed	4 (7%)	
Outside - level of disturbance from turbine noise		
Do not notice	10 (16%)	55%
Notice but not annoyed	24 (39%)	
Slightly annoyed	12 (19%)	
Rather annoyed	9 (15%)	44%
Very annoyed	6 (10%)	
Inside - level of disturbance from turbine noise		
Do not notice	29 (47%)	66%
Notice but not annoyed	12 (19%)	
Slightly annoyed	10 (16%)	
Rather annoyed	5 (8%)	32%
Very annoyed	5 (8%)	
Noise complaints		
Have registered complaint about noise	9 (15%)	
Have registered complaint about turbine noise	6 (10%)	

4. Discussion

The measured long-term receptor immission values summarized in Figs. 5, 6, and 7 provide an overview of the environmental noise levels experienced in the study area, as well as how these levels vary with wind speed, which affects both turbine-

generated noise and background noise. The noise exposure at the five receptor locations was generally ordered by the distances to nearby turbines, as expected from Table 1. Slight variations did exist, as with Location C having equal or greater exposure than Location D (the location with the nearest turbines) in the winter campaign. At the fixed wind speed of Figs. 5, 6, and 7, noise exposure was consistent between the autumn and winter campaigns, but overall A-weighted (Fig. 5) and low frequency (Fig. 6) noise was slightly lower during the summer campaign. This may be illustrative of changing sound propagation conditions from season to season.

Although no parked-turbine measurements were made, the data from no-turbine background locations provide a frame of reference that corresponds reasonably with the pre-development study of the site (Sec 3.1). At certain receptor locations (most substantially C and D) and at meaningful wind speeds, an appreciable margin exists between the best-fit L_{eq} noise level at the receptor location and that at the comparable background location, at all three frequency ranges of study. For instance, in the winter campaign with 7 m/s at 10 m wind, the best-fit results at Locations B, C, D, and E each exceeded the background location value of 41.2 dBA by at least 7.0 dBA. The margin for these four locations at the chosen low frequency range reached at least 7.5 dB, while the margin in the chosen infrasound range was less substantial with a minimum of 4.3 dB.

Prior to development, the local municipality adopted a siting regulation (Town of Wethersfield 2006) that limits audible turbine noise to a maximum of 50 dBA “for any period of time” when measured at a sensitive receptor that has not granted a noise easement; it is unknown whether such easements are in place at any of the receptor properties in this study. Since the no-turbine noise levels measured in this study appear to be representative of pre-development background noise levels within the wind park (Sec. 3.1), this 50 dBA value may have been exceeded at moderate to high wind speeds (7 m/s at 10 m and higher) on a best-fit basis at multiple receiver locations, principally in the autumn and winter campaigns. Because of the wide scatter of individual data points at each wind speed, levels exceeding the best-fit value “for any period of time” may be even more likely. Although this municipal limit provides a local benchmark for interpreting these results, location-specific parked-turbine measurements would be the most appropriate way to decisively compare wind turbine noise immission with an enforceable regulatory standard.

Given the constraints of the current project, several aspects of current interest in wind turbine noise were not studied in detail. These include shorter (< 1 s) periods suitable for identifying impulsive or amplitude-modulated noise and its effects on annoyance; additional overnight noise measurement and multi-level meteorological measurement to better capture stabilized atmosphere or other infrequent propagation conditions; and integration of wind park operational (SCADA) data from a willing utility to better characterize conditions at each individual turbine. An improved wind screen arrangement, including secondary windscreens and ground microphones, would have allowed more robust collection of usable low-frequency and infrasound data with less contamination from wind-induced self-noise.

Finally, at the conclusion of this study, an avenue for further analysis is apparent. The current data set could be enhanced with the addition of a site-wide model of turbine sound power and noise propagation, as has been employed by prior studies. A calculated noise immission value for each residence in the community survey may

characterize underlying exposure better than the variable short-term field measurements collected here, and may therefore also provide better insight into resident satisfaction and annoyance from wind turbine noise.

5. Acknowledgements

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