Wind Farm Noise: 2009 in Review

Research, public concerns, and industry trends

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Introduction

During 2009, the Acoustic Ecology Institute has been tracking public concerns about wind farm noise, while also studying new research papers and industry trade journals and reports in order to get up to speed on this emerging controversy. AEI's approach has been the same as we've taken to ocean noise issues since 2004: to do our best to cut through the rhetoric and hyperbole from advocates on both sides of the issue and get a clearer sense of the state of understanding of these noise impacts, in order to help inform emerging public policy choices[1]. With wind farm noise, as with ocean noise, the more we learn, the more obvious it is that there is much we still do not know. And, it's not nearly as simple as either side in this increasingly rancorous debate appears to think it is.

This AEI Special Report serves as an update and supplement to my initial work on this topic from late 2008, still available on our website at AcousticEcology.org/srwind.html. While the focus of this report is to digest what we learned in 2009, it also will include some over-arching themes and bigger-picture context that I hope is useful as an introduction to those who are new to the consideration of the effects of wind farm noise on people living nearby. Some of these themes have emerged over the course of this year as I've learned more, and have been introduced on AEI's news and science feed at AEInews.org.

The key messages of this report can be boiled down to four themes.

- First, it is clear that many people, in all parts of the country, have been dramatically impacted by the noise of wind farms near their homes. To dismiss all these people as cranks, or as hyper-sensitive social outliers, does a disservice to constructive public discourse, and short-circuits our opportunities to learn from their experiences as we continue to develop new wind farms.

- Second, it is also clear that wind farm noise is truly not that bothersome to most people who hear it or live near it, and that the vast majority of wind farms never generate any substantial ongoing noise issues. Concerns that dominate public discourse and activist web sites can seem to accentuate the hardest to quantify issues (such as direct health effects, especially of low-frequency noise), while magnifying the extent of problems as communities consider new wind developments.

- Third, the nature of the sounds made by wind turbines make it especially difficult to rely on reassuring "noise limits" as proposed by states, counties, or townships. Several factors contribute to this dilemma. Noise propagation varies greatly with changing wind and atmospheric conditions; there are many different ways to average noise recordings, some of which can lead to noise levels much higher than local officials may think they are allowing; the pulsing nature of turbine noise is inherently more attention-grabbing and more easily disruptive than road or industrial noises; and finally, there is much we have yet to learn about the factors that create the most troublesome turbine noises, including pulses and low-frequency sound.

- And fourth, and perhaps most important yet least appreciated: we are facing some social choices that may be difficult to make. While broad-brush studies report no simple cause-effect between wind farm noise and various measures of impact (health, annoyance, property values), it is also clear that a minority of those nearby do often experience dramatic, negative impacts. How many such affected neighbors are we willing to accept? 5%? 20%? We can no longer pretend this more affected minority doesn't exist; it's time to choose how much to adapt wind farm planning — or operations — in response to these impacts.

I invite you to be in touch with any comments, suggestions, or critiques of what you read here. I also encourage you to read this report with an open mind and let your own understanding of these issues expand to include some new perspectives. We're all learning as we go!

Jim Cummings, Executive Director, Acoustic Ecology Institute

Nature of the Noise Issues

Many people living near wind farms, in all parts of the country, report that noise from the 250- to 400-foot tall turbines is much more disruptive than they had been led to believe by project planners. Over the past couple of years, industry representative have been far less likely to claim that turbines will be inaudible, but there is still a tendency to assure residents that likely noise levels (generally 40-50dB) will be easy to live with. Many rural residents share the shock of one woman in Maine who discovered that, at night in rural areas, "40dB is loud!"[2]

How loud *are* current-generation wind turbines? Manufacturer specs for today's 300-400 foot, 1.5-2 megawatt wind turbines indicate that the "source level" of their noise emissions are generally 98-104dB[3], roughly the same loudness as a chain saw or stereo at maximum volume[4] (though turbines obviously have a very different — and potentially less penetrating — type of sound). With this in mind, it makes a certain sense that industry sound models and public assurances would suggest that turbines should have negligible impacts beyond several hundred feet. However, we must remember that the noise source is not at ground level, quickly dissipated by trees and buildings; rather, it emanates from high above the ground, with a direct, unobstructed path to a very large surrounding area.

It's not hard to find reams of compelling first-hand accounts of wind farm noise online these days[5], so there's little need to present a long litany here. More useful, perhaps, would be a concise summary of the types of problems reported by people living within earshot of turbines.

First and foremost is sleep disruption. There is little question that noise levels more than 5 or 10dB over the still late-night ambient levels of 20-30dB can wake people. Some wind farm neighbors report many nights of getting only four or five hours sleep. Less appreciated is that low levels of noise also triggers non-waking arousal during sleep which disrupts normal sleep stages, leaving the sleeper less well-rested upon waking in the morning.[6] Many wind farm neighbors complain of headaches, irritability, trouble concentrating, and similar symptoms that are often rooted in lack of solid night-time rest.

For some people, turbine noise is also disruptive during the day. People report not being able to spend time in their gardens, or that their children play outside less. Metal workshop roofs can rattle in low-frequency sound waves, making it difficult to stay and work.

A smaller number of people report strange pressure in their ears or chest, or other physiological responses that can occur at any time of day or night when turbines are operating; these may be associated with particular wind or atmospheric conditions, or with a pre-existing physiological sensitivity or imbalance.

In the most extreme cases, families are forced to move from their homes to escape the effects of the ongoing noise disturbances. These are not necessarily people living extremely close to turbines; such unlivable situations have occurred from 1000 feet to over a half-mile from the closest turbines. Some wind farm developers have actually bought out neighbors that were especially impacted[7], though most are left to make the best they can with a piece of property that will be difficult, if not impossible[8], to sell. I have not seen any comprehensive listing of residents who had to move, but such reports are becoming more common in the US, Canada, and the UK, totaling perhaps three to six per year.

Finally, and hardest to address, are concerns about low-frequency noise. Here at AEI, we have yet to fully assess these issues, since there is enough clear information regarding audible noise to work with for now. Complicating assessment of likely impacts, low-frequency noise varies more than audible noise in both propagation patterns (which can be affected by geology as well as topography and air conditions) and in how sensitive different people are to both audible sound and sub-audible acoustic energy (infrasound). Certainly there are people whose homes seem to vibrate in some sort of resonance when nearby turbines are active; whether these are low-frequency effects, or a resonance within the structure from low-level audible noise, is sometimes hard to ascertain. It also appears that

larger turbine blade diameters may be associated with highly amplitude-modulated infrasound; such impulses, even of sound well below hearing range, may be perceptible, either on the edges of audibility or as a physical sensation[9]. Much less clear is whether such low-frequency sound, at relatively low levels (compared to those experienced in, say, a factory or jet fighter), can itself cause health effects; suffice to say, there is much debate on this question, and while the balance of evidence suggests that health impacts are unlikely to be widespread, it's premature to say — as the industry suggests — that the case is closed.

Most of those who are sharing their stories do so not because of some underlying dislike of wind energy; indeed, many were supporters of local wind projects who simply believed the reassuring promises of wind companies. Rather, they hope that by sharing their nightmares of disrupted lives, they might be able to help others avoid a similar situation. Over and over when listening to these folks, you hear the refrain, "if they'd only built them a little farther away." Some suggest a half-mile would likely have worked for them, while others say there are some turbines out to closer to a mile that are troublesome. In stark contrast to industry assumptions that those complaining are simple NIMBYs, the fact is that most of those who are struggling with noise are more than willing to *see* turbines; they just don't want to hear them so often. While some people end up angry, and may speak from a place of distrust or spite (and after all, we all know that every town has its share of cranky naysayers who always feel put upon), many more simply want to help others understand that it's not always easy to adapt to the types of noises that wind turbines make. When other communities hear the same comforting assurances that they had heard, there is a desire to be sure that the whole picture is made clear.

(Note: Half-mile limits are sometimes proposed as a precautionary response to noise concerns, but there are definitely many people between a half and three-quarters of a mile who are affected, as well, including some of the more severe noise issues[10]. While adoption of half-mile setbacks would alleviate many of the worst problems, it is not enough to eliminate routine noise issues. Also, while acknowledging that occasional audibility at longer ranges cannot, in practice, be eliminated, it's worth noting that many cases of occasional audibility out to several miles have been reported, and some new questions are arising about over-water transmission from wind farms recently commissioned along the Great Lakes shoreline. Some reports and concerns about low-frequency sound transmission extend to up to two miles; though there is very little on-the-ground data to clarify how common or strong such long-range transmission is, independent acousticians in the US and New Zealand are currently investigating this question.)

See the later sections of this report on Noise Limits, Social Considerations, and Resolving the Science/Experience Paradox for more perspective on the concerns shared by many of those impacted by wind farm noise.

Scope of the Problem

While wind farms with significant local discontent about noise are clearly widespread — including projects in Maine, New York, Pennsylvania, Wisconsin, Michigan, Missouri, Texas, North Dakota, Washington, and Oregon — the bulk of online activist information centers on a few towns that have become "poster child" cautionary tales about wind farm noise. Mars Hill, Maine and their farmhouses at the bottom of a ridge; Fond du Lac Country, Wisconsin where turbines were plopped down across a rolling landscape of farms; Dufferin County, Ontario, where a developer bought at least two houses after residents abandoned their homes; Julian and Jane Davis of Lincolnshire, England, who abandoned a home 3000 feet from turbines that real estate agents then refused to list for sale because of the noise[11]. These tales ricochet around the world on local activist websites that spring up in nearly every region where a new wind farm is proposed.

Yet these activists may be surprised to hear that while perhaps a dozen or so American wind farms have spurred significant noise issues[12], in 2008 129 new wind farms went online in the United States, with close to 136 more added in 2009.[13] This two-year surge has doubled America's installed wind capacity, which suggests that around 400 wind farms are now operating nationwide[14]. Yet even the comprehensive online wind farm activist sites, which archive any and all news reports of issues ranging from tower collapses to fires to noise to bat and bird kills, contain no mention of noise issues at most of them[15] (though it's not uncommon to find reports of noise concerns raised at hearings prior to commissioning, but then no stories of issues later[16]).

Of the ten biggest wind farms in the United States, only two (Maple Ridge Wind Farm on Tug Hill, NY and Horse Hollow, TX) have triggered widespread local complaints, and one other (Buffalo Gap, TX) had some scattered reports of noise issues, but not nearly so persistent;[17]

It's important to note here that the lack of local news coverage of noise complaints (local papers are the source for most of the national activist site archives) does not necessarily mean no one is bothered. It's altogether possible that many of these wind farms are affecting some nearby residents, but that the total numbers of people affected are too low to either catalyze local support for voicing concerns, or to justify media coverage. For example, while there are 113 people per square mile in Albion, NY, a town considering a wind farm, there are only 17 people per square mile in Roscoe, Texas, home to one of the nation's biggest wind farms.[18]

Certainly, many wind farms are sited far enough from any homes to pose absolutely no threat of significant noise impact. For example, the Dry Lake Wind Farm in Arizona, which was commissioned in late 2009, is several miles from any residence. In general, it's rare to hear of any serious noise complaints from turbines further than three-quarters of a mile from a home, though some low-frequency issues have occurred out to between one and two miles.

Industry reps are also used to hearing inflated reports of noise issues. The lawyer who defended the Horse Hollow wind farm developers in a nuisance lawsuit recalls a plaintiff he described as "a wonderful woman, a salt-of-the-earth type," who testified that the sound of the wind turbine on her land was equivalent to the sound of a B-1 bomber. "Well, I knew that was impossible," he notes, "A B-1 bomber makes a sound around 101 decibels. I think that when people don't like the wind turbine, they become bigger, they become louder and they become uglier in their minds." In measurements made at plaintiff's residences, turbine noise averaged 28 dBA at a distance of 1.7 miles from the wind turbines, and 44 dBA at 1,700 feet[19]. In an 11-1 verdict, the jury found that these noise levels did not constitute a nuisance. (It is worth noting that 28dB can be audible on a quiet Texas night, and 44dB could be well above background ambient, if wind shears are present.)

With hundreds of wind farms operating with virtually no complaints at all, it's easy to see why the industry is so slow to take noise complaints seriously when they do arise. When residents near the Willow Creek Wind Farm in Oregon were quoted in a local news report, noting specific noise problems including sleep disruption, high measured noise levels, and frustration with company assurances that

the turbines would be no louder than a refrigerator, a company spokesman responded, "We don't believe there is anything to it."[20]

Conversely, even casual monitoring of online wind farm news will confirm that concerns about wind farm noise are not limited to situations similar to those in the wind farms that have become trouble spots. Many people in areas where wind farms are being proposed have become extremely concerned about both faint audible noise and possible low-frequency noise, even though the wind farms will be several miles away. It's important to realize that not every wind farm becomes a horror story, and that the vast majority of severe noise issues occur at under a half mile, with significant noise disruption hardly ever occurring beyond three-quarters of a mile.

Noise Limits

Over the past few years, regulatory authorities at all scales (township, county, state, provincial, federal) have wrestled with the question of how best to design guidelines for siting of wind farms. Most jurisdictions have centered their rules on distance setbacks, which commonly range from 500 feet to 550 meters (1800 feet). In many cases, however, the rules also set a maximum sound level that is allowed; when both distance and sound standards are in place, some jurisdictions define the limit as the closer of the two, and some the farther. While distance limits are far easier to design and work with, statutes that set a maximum sound level are often considered preferable, by both industry and community groups. From the industry's perspective, the use of sound limits provides more flexibility in designing wind farms, since distance-only setbacks don't take into account the ways that sound travels differently upwind and downwind. Community groups are often focused on the noise impacts of proposed wind farms, so they also prefer a clear noise standard.

However, when the state or county sets a maximum noise level, the result is not as clear-cut as they may think. Three key factors can wreak havoc with well-intentioned noise limits. First, and often entirely overlooked by local regulatory bodies, is that the time period over which noise levels are measured and analyzed can make a huge difference in the practical effect of any given noise limit. Second is that the sound propagation models that the industry uses to place turbines in a given location, while generally accurate, are often not applicable in some fairly common atmospheric conditions. These two factors combine to create various situations in which sound levels exceed what manufacturers expected, or even when in compliance with regulations, can create bothersome sound levels for nearby neighbors. And finally, the nature of wind turbine noise sets it apart from many other noise sources (such as traffic noise or a factory), so that limits that may work for other sources fall short with wind farms.

Noise measurement metrics

The standard procedures for measuring, assessing, and analyzing noise include several key elements; it's important to understand each of these in order to know what the rules will require.

Weighting scale

- **dBA**, or dB(A), is a way of measuring sound that reflects human hearing: frequencies we hear well are given extra weight, while ones we do not hear so easily are discounted.
- **dBC** gives extra weight to lower frequency sounds, and is used to asses whether there is significant acoustic energy at frequencies near and below the low end of human audibility. It is generally accepted that if dBC exceeds dBA by 20dB or more, then people may experience some excessive low frequency noise effects (vibrations, etc.).
- **dBG** focuses in on very low frequency and infrasound (well below human hearing). When this is high, it may indicate some long-range vibration impacts. Some acousticians suspect that the perceptual/experiential troubles related to amplitude modulation may be clarified by assessing dBG, and its changes during the pulsing of turbine noise.

Averaging time

- **DN** (or **DNL**) Day-night level. This includes recordings taken through an entire 24-hour day and night. If no other time-related factors are included (such as "5-min" or L10), then a DNL of 43dB would mean that this is the average sound level over the entire day and night. As might be expected, daytime sound levels will be notably higher, and actual sound levels in the middle of the night much lower.
- **N** (or **NL**) Night level. This is a sound measurement taken only at night; while much more useful in setting noise limits, it typically includes early evening and pre-dawn, both of which often are louder than the middle of the night, thanks to frog and/or bird choruses and more human, so use of a night average should also be used advisedly if the goal is minimizing disruption in the middle of the night.
- **DEN (or Lden)** An 24-hour averaged (equivalent sound) "day evening night" sound level; used

in European standards. Sounds recorded in evening are given a 5dB extra weighting, and night sounds 10dB extra, in determining compliance with these 24-hour standards.
- Shorter averaging times (5min, 10min, 30min, 60min etc.) These are sometimes used to better identify noise trends over the course of a night (or day). In some cases, regulations are based on the quietest of these periods, which is likely the most protective approach.

L10, Leq, L90

When longer averaging times (e.g., all night) are used, some acousticians like to specify the following metrics, which can help in visualizing the variability of the noise levels during the period being considered, or provide a sense of the loudest and quietest parts of the period.

- **L90** or L_{90} This is the dB level that is exceeded 90% of the time; that is, it represents the quietest 10% of the time. It's sometimes used to establish the likely baseline of night time quiet.
- **L10** or L_{10} This is the dB level that is exceeded only 10% of the time; that is, it represents the loudest 10% of the time. L10 is sometimes used in lieu of tracking maximum sound levels, as it excludes anomalously loud sound events (e.g., the a plane or car passing a recorder measuring local noise levels, or an animal calling close to the recorder)
- **Leq** or L_{eq} Similar to an average, this is value is calculated to be the "equivalent sound level" if all sound in the averaging period is combined, and then spread out through the period.

Each of these above metrics represents different ways of assessing noise levels; in practice, they are combined and reported using nomenclature such as:

$45dBA_{DNL90}$

$85dBC_{N10}$

$34dBA_{N(10\text{-}min)}$

Being conscious of choices made when averaging noise readings

Perhaps most important is being clear about the period over which recorded noise levels will be averaged. This choice is made both in setting the limit (e.g., while measuring existing ambient noise) and when monitoring to assure wind farm noise levels are in compliance with the limits.

In many cases, noise limits are set with some consideration for previously measured nighttime or 24-hour ambient noise levels; here again, the limit can be set based on average (eq) or lowest (5-min or hour or L10) sound levels. From there, rules may allow turbines to be five or 10 dB louder; also common is a semi-arbitrary limit of 40-50dB, or nighttime limits of 35-45dB[21]. Many times, a local standard of 45 dB requires only that the average sound levels over the entire day and night not exceed 45 dB. In some jurisdictions, turbine noise is not supposed to exceed the limit, even momentarily.

If existing nighttime ambient is measured and averaged over the entire night, the standard will not reflect the true sound levels during the quietest part of the night; early evening frog choruses and human activity, along with pre-dawn bird choruses, tend to elevate average sound levels well above the actual sound levels during the deep nighttime hours of 11pm-4am. In practice, it's not uncommon for turbine noise of 40 or 45 dB to be 15 or even 20 dB louder than the true ambient noise level during the quietest parts of the night. These are the situations in which the turbine noise may become especially problematic for nearby neighbors.

Variability in sound propagation

During permitting, wind companies must present data to assure regulators that the sound levels at residences near their turbines will meet the local noise requirements. They do this by using sound models into which they input information specific to the location (noise levels of the turbine models being used, wind patterns, terrain topography and plant cover, etc.). The result is a neat and tidy diagram showing what sound levels will be expected around the individual turbines, and in the landscape within and around the wind farm as a whole. These models are being continually improved, so as to better incorporate the effects of many turbines in combination, new data from the field

(especially from instances in which the models had been inaccurate), and the like. The models are used to place turbines in the landscape in a pattern designed to assure that houses will not be exposed to sound above the local limits — but importantly, the siting is often finely tuned to just barely come in under the noise limit; therefore, any variation from the model's predictions can be problematic for neighbors (and especially so if the limits are set above likely true ambient levels, or are based on long-period averages).

Inevitably, any model will have its limitations. In many cases, sound models over-estimate the noise actually received in the field, thanks to more turbulence in the air and interference from the ground than the models assume (it is common for modelers to include some conservative assumptions to minimize the chance that they will underestimate impacts). On the flip side, there are clearly times when noise levels in the field exceed those predicted by sound models; these situations, if they occur with any regularity, can cause sleep disruption or other annoyance reactions that lead to community agitation.

Increasingly, acousticians are working to zero in on the specific wind conditions that are occurring during the times when neighbors are most bothered by turbine noise, so that they can adapt their turbine operations to reduce noise in this situation.[22] This is still a relatively new line of inquiry, and there are no clear summaries of these studies available; until comparisons can be made across several wind farms, such studies will be considered preliminary.

The most commonly noted situation in which turbine noise becomes problematic for neighbors is in a stable nighttime atmosphere. This means that there is a layer at ground level in which the wind is nearly still, with a layer of stronger wind above ground level yet below turbine height, with little turbulence between these layers; in these situations, the background ambient noise can be very low (20-30dB) at people's homes, while the turbines are operating and making noise. In some cases, the higher winds aloft may be carrying the turbine noise further than the models expect, thanks to the minimal turbulence. It is also not uncommon that the turbines can be operating at or under a noise limit of 40dB or 45dB (or even 36dB[23]), yet be much louder than the background, and so be especially irritating. In addition, there is some indication that the pulsing character of the noise can be more dramatic when wind speeds are lower at the bottom of the blade diameter than at the top, again not unlikely in these nighttime conditions.

The unusual nature of wind turbine noise

Amplitude Modulation

Many neighbors report the pulsing, beating character of the noise as being the key factor that makes it harder to ignore or get used to than other noises. This pulsing is known as "Amplitude Modulation" (AM): amplitude is the loudness, which is changing – modulating – over the course of each couple of seconds. When the AM is more than 5dB, the variability becomes clearly noticeable; it can be most troublesome when the quieter end of the pulse is not quite audible (for example, at relatively long distances).

Some recent field studies indicate that while the AM occurs of the course of 1 to 2 seconds between peaks (or troughs) of the noise level, the increase in noise occurs in only a tenth of a second or so, meaning that it is perceptually experienced as an impulse of sound, which is much more attention-grabbing than a gentle sinusoidal swaying of sound.

Several recent studies have presented models and measurements that continue to address outstanding questions about the directionality of AM. It appears that AM is most pronounced to the sides of turbines; this may be due to the motion of the blades or because noise coming off the trailing edge of the blades is directional. An interesting finding in one recent detailed recording study was that while the noise levels were lower to the side, the AM was only noticeable there[24]; this makes me wonder whether one reason that AM is troublesome is that it may occur in zones where the turbines are otherwise largely imperceptible.

Grab-bag of sounds

Another aspect of wind turbine noise that neighbors often mention is the many different sounds that are heard at different times: thumping, whistling, rumbling (the "train that never arrives" sound), as well as the pulses.

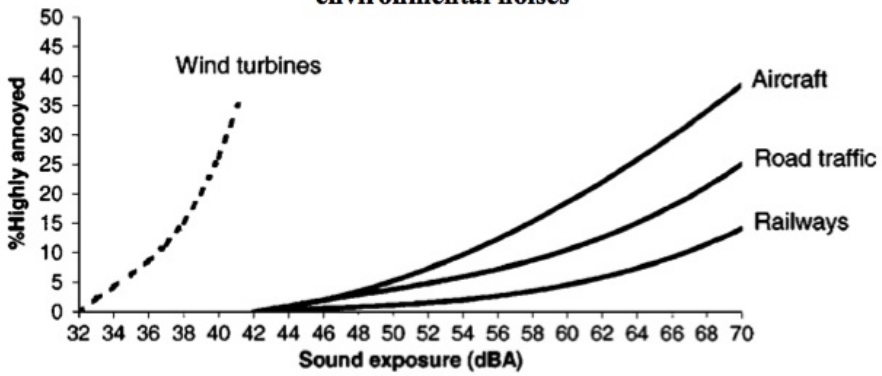
Low-frequency sound or physical/palpable "pressure waves"

Though it remains hard to quantify, many neighbors report various experiences of low-frequency sound or vibration around some wind farms. It's not clear if these are caused by particular geological situations, or by mechanical problems, or by the growing size of turbine blades. While we cannot make any concrete conclusions at this point, low frequency effects certainly bear ongoing consideration.

Perhaps related are some reports of what are experienced as "pressure waves" from turbines. In these reports, people speak about feeling the pressure waves in their chests, or that the waves rattle metal roofs. One compelling report from a hunter in Vermont notes that from "a half-mile to over 2 miles away, the sound is a low, dull, penetrating, throbbing series of never-ending pressure waves - hour after hour, day and night, sometimes for days on end, like Chinese water torture. While I was hunting there this year, I noticed that I didn't need a compass to orient myself in the deep, dark woods 2½ miles away so long as the turbines were throbbing.[25]"

All these qualities of the sound creates more annoyance at lower dB levels than other types of sounds
These unusual qualities of wind turbine noise likely explain another important research finding. Noise control experts have long used annoyance curves to predict what sound levels will trigger significant annoyance in nearby residents; these curves link rising sound levels to increasing proportions of the population reporting being annoyed. Several studies have now shown that annoyance curves for other noise sources are not applicable to wind turbine noise: around wind farms, equivalent levels of annoyance are triggered by much lower noise levels.

Figure 6: Annoyance associated with exposure to different environmental noises



This chart is copied from the 2009 report by the Minnesota Department of Health, entitled *Public Health Impacts of Wind Turbines*. It was originally published in Pederson and Waye, Perception and annoyance due to wind turbine noise—a dose-response relationship. J. Acous. Soc. Am. 116:3460. 2004.

Noise Limits: Useful benchmark, but the experience of sound is hard to quantify

All in all, as you can tell, noise limits and regulations are useful targets, and provide a way for communities to craft their own individual approach to shaping the soundscape experienced by residents. But, noise regulations remain a crude tool, and it's important that everyone involved realize that the experience of sound in the landscape can never be reduced to a particular decibel level.

For example, it's instructive to think a bit more deeply into some of the comparisons that are commonly used to describe likely wind farm noise levels. To reassure neighbors, wind companies often note that a 40-50db noise is similar to that made by a refrigerator, or light traffic on a road 50 feet to

100 feet away. This is true enough, as far as it goes. But consider: do you sleep next to your refrigerator? If you live in the country, would you readily adapt to steady light traffic on a road only 50 feet away? Add in the fact that turbine noise is often much more variable, pulsing, etc., than a refrigerator, and you begin to get a sense as to why simple dB levels are not really all that descriptive.

Even after a particular noise level is codified, it is likely that many communities will continue to find that wind farms are a new and hard-to-quantify element in the local soundscapes. As communities and acousticians continue to look more closely at the situations in which turbine noise has been particularly disruptive or has diverged most notably from the predictions of current noise modeling, we will have the opportunity to craft noise and operational regulations that better reflect the nature of this unique sound source.

Research results of note from 2009

Thanks to the increasing public, regulatory, industry, and scientific interest in the question of noise effects near wind farms, many fascinating new studies and overview reports were published over the past year. Here we briefly summarize many that anyone who is working on wind farm siting issues should know about; in many cases, we also provide a link to download the full paper, and to read AEI's more extensive online summaries of each paper. While AEI's online summaries are a useful way to learn more, we also encourage you to download any and all that pique your interest, in order to dig in more fully; AEI's web pages include links to the source papers, when available.

Note: Most of these studies are not formally peer-reviewed. While this is sometimes used as an attack on papers that are used by groups suggesting a need for more care in wind siting, the large government reports are also generally not peer-reviewed. In general, if a scientific journal is included in the citation below, then peer review can be assumed to have taken place. Presentations at conferences such as Wind Turbine Noise and Internoise are not peer reviewed; neither are reports issued by trade organizations or government agencies. This does not mean that the information presented in non-peer-reviewed papers is unworthy of consideration; rather it simply suggests that careful scrutiny of the data and interpretations are in order, since the author may not be forced to present the data with the same degree of caveats and references to other literature that would occur in peer-reviewed papers.

Effects on Neighbors (noise, annoyance, health, property values)

World Health Organization. Night Noise Guidelines for Europe.
Download: http://www.euro.who.int/eprise/main/WHO/Progs/NOH/Activities/20040721_1
AEI summary: http://aeinews.org/archives/429
This 184-page report offers a comprehensive overview of research into the various effects of noise on sleep quality and health (including the health effects of non-waking sleep arousal), and is recommended reading for anyone working with noise issues. The WHO now recommends a maximum year-round outside nighttime noise average of 40db to avoid sleep disturbance and its related health effects. The report notes that only below 30dB (outside annual night-time average) are "no significant biological effects observed," and that between 30 and 40dB, several effects are observed, with the chronically ill and children being more susceptible; however, "even in the worst cases the effects seem modest." Elsewhere, the report states more definitively, "There is no sufficient evidence that the biological effects observed at the level below 40 dB (night,outside) are harmful to health." At levels over 40dB, "Adverse health effects are observed," and "many people have to adapt their lives to cope with the noise at night. Vulnerable groups are more severely affected." *Note: the annual average noise level used in WHO recommendations may be difficult to adapt to most wind farm noise regulations. Few localities or wind developers have the resources to measure noise year-round, and most regulations focus on shorter time periods. The State of Vermont, for example, has chosen a limit that is similar to the WHO recommendation (30dB inside the bedroom), but measured as a one-hour average.*

Minnesota Dept of Health. Public Health Impacts of Wind Turbines.
Download: http://energyfacilities.puc.state.mn.us/resource.html?Id=24519
AEI summary: http://aeinews.org/archives/456
This state agency report provides a good overview of our current understanding of wind farm noise propagation and impacts, with particular attention given to possible low frequency noise issues. The report makes no dramatic recommendations, though the data presented suggests that audible and low-frequency noise could affect neighbors within a half mile to mile. Among the key pieces of information contained in this report, gleaned from previous research studies:

- A reminder that the 2007 report on wind farms and human health from the National Academies of Science concluded that "noise produced by wind farms is generally not a major concern beyond a half mile" (i.e., under a half mile can be problematic).
- Some individuals have extraordinary sensitivity to low frequency sound, up to 25dB more sensitive than presumed (average) thresholds at some frequencies
- Some people can dismiss and ignore repetitive but low intensity noise, while for others, the signal will grow and become more apparent and unpleasant over time. These reactions may have little relationship to will or intent, and more to do with previous exposure history and

personality.

Christopher Hanning. Sleep disturbance and wind turbine noise.
Download: http://www.wind-watch.org/documents/wp-content/uploads/Hanning-sleep-disturbance-wind-turbine-noise.pdf
AEI summary: http://aeinews.org/archives/277
This report, by a UK MD whose specialty is sleep disorders, takes a comprehensive look at factors affecting sleep disturbance caused by nearby wind farms, and is highly recommended reading for anyone working to develop regulations at the local or state level. Hanning's primary point is that external noise need not *wake* a sleeper to cause problems, and that repeated "arousals" can break the most restful periods of sleep. He notes that "The sleep, because it is broken, is unrefreshing, resulting in sleepiness, fatigue, headaches and poor memory and concentration." These are precisely the symptoms often reported by people living near wind farms. Hanning notes that arousals can occur in response to noise events as low as 32dBA, and that the elderly are more susceptible to arousals.
This report was prepared on behalf of Stop Swinford Wind Farm Action Group; however, the author's credentials in this area of his expertise are clear (unlike some informal reports, written by trained scientists or doctors, but outside their area of expertise).

Colby, Dobie, Leventhall, Lipscomb, McCunney, Seilo, Sondergaard. Wind Turbine Sound and Health Effects: An Expert Panel Review. American Wind Energy Association and Canadian Wind Energy Association.
Download: http://www.awea.org/newsroom/releases/AWEA_CanWEA_SoundWhitePaper_12-11-09.pdf
Detailed AEI summary: http://aeinews.org/archives/584
This report, which purports to be a comprehensive look at health effects reported near wind turbines, includes some good information, but is limited by its excessive focus on discounting one particular (and controversial) theory, "Wind Turbine Syndrome," and related ideas about the effects of low-frequency noise. While effective in this critique[26], this study completely omits consideration of the most widely-reported effect of wind farm noise, sleep disruption. The authors repeatedly stress that annoyance is not a health effect, which is true enough as far as it goes, though it is also well known that annoyance, stress, and sleep disruption can contribute to physiological effects. Likewise, the authors emphasize that sound levels around wind farms (and especially low frequency sound) is no higher than in cities, and that "the sound emitted by turbines in not unique;" yet there is only fleeting mention of the qualities of wind turbine noise that are clearly different than other noise sources, and of studies that find that turbine noise triggers annoyance at much lower sound levels, and no consideration of the question of whether urban and suburban noise levels are an appropriate benchmark for rural communities. The papers' conclusions are also striking: the authors make a point of discounting the relevance of the World Health Organization's night noise guidelines, and likewise conclude that since reports of health impacts are so far only from uncontrolled studies, and appear to be relatively rare, that further study is unwarranted.
This report was prepared on behalf of the two largest North American wind industry trade groups; the authors all have good credentials, though the Expert Panel did not appear to include anyone who has raised any questions about wind farm noise in the past (i.e., while "expert", it was not necessarily balanced).

Pederson and Waye: Continuing analysis of large resident surveys near wind farms in Denmark and Sweden
Eja Pederson. Effects of wind turbine noise on humans. Third International Meeting on Wind Turbine Noise, Aalborg, Denmark, June 2009.
Kerstin Persson Waye. Perception and environmental impact of wind turbine noise. Presentation at Internoise 2009.
AEI summary: http://aeinews.org/archives/456
These two researchers have been turning out interesting papers for several years, based on large surveys of residents near several wind farms in Scandinavia. This year's papers provide a bigger-picture view, drawing on results from three different wind farms (totaling nearly 1800 people), and are very well worth seeking out to read; alternatively, AEI's summaries include much more important information that we can include here.

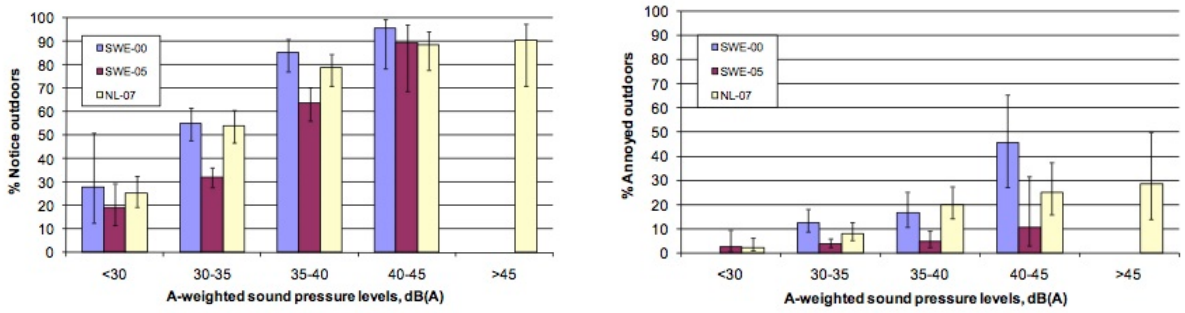
Pederson's review indicates clear thresholds for increased annoyance at sound levels often experienced by wind farm neighbors, and also illustrates the subtleties inherent in making generalizations based on ambiguous data. The author makes a key introductory point: that wind farms "often are placed in rural settings considered places with low exposure (to) environmental stressors….in such a setting, even when the levels are comparably low, (wind farm noise could) be perceived as a potential health risk."

The heart of the studies shows a correlation between sound level and annoyance, with an increasing percentage of people annoyed as noise levels increase. This effect was clearly stronger in the two flat, rural areas, than in a study that took place in a suburban, rolling landscape that had more other noises present. A dramatic increase in the proportion of people annoyed by turbine noise took place when the noise was over 40dB(A); here, 25-45% reported annoyance in rural settings, and 10% in the suburban area. At 35-40dB, annoyance ranged from 16-20% in rural settings but was only 5% in suburban; at 30-35dB, annoyance hovered around 10% in rural areas.

(Note: Some interpretations of this data set by industry analysts[27] combine the rural and suburban results; since the suburban sample was larger, this lowers the annoyance averages. If you are trying to understand impacts in a rural area, this is important to bear in mind. Also, citing the overall average annoyance level in the entire study population of 1100-1800 people will create a misleadingly reassuring picture, since there are many more people living in more distant zones and exposed to very low sound levels; more useful is to focus on the sound levels at which annoyance tends to rise, and to work hard to remain below these levels.)

The studies showed no direct correlation between noise levels and health effects related to stress (including headaches, tiredness, tenseness, and irritability); this is not surprising, since at all noise levels, a majority of the population was not annoyed, so also not likely to be stressed. Among those experiencing annoyance, there was a correlation with stress effects, but it was far from universal (correlations generally in the 1.25 range).

In parsing the data from the three studies also addressed by Pederson, above, Waye adds two key pieces of information: first, all these wind farms consist of relatively small turbines, by current standards: 500-800kW (up to 200 feet hub height). Second, our consideration of annoyance thresholds at various dB levels is greatly enhanced by a graph showing that, in addition to those annoyed at each sound level, another 40-70% of the population could HEAR the turbines, but did not report annoyance. For example, at 30-35dB, over half of rural residents reported hearing the turbines, while only 8-12% were annoyed; at 35-40dB (within most global regulatory limits), 85% heard them, while just under 20% were annoyed; and at 40-45dB (within common US regulatory limits), 95% heard them, while 45% were annoyed.



Left graph: % that can hear the turbines at each sound level
Right graph: % that is "rather" or "very" annoyed at each sound level
Maroon (center) bars are the suburban site; purple and yellow are the rural sites

Finally, Waye addresses a commonly reported finding: that annoyance levels are higher for wind turbines than for noise from less dynamic industrial sources, such as factories. She cites a study that shows that annoyance when indoors is pretty much the same, but that outdoors in rural settings,

annoyance is significantly higher at sound levels above 35dB. Waye suggests that in rural settings, recreational and "restorative" aspects of outdoor experiences are impinged upon by wind farm noise.

Johnburg, Wisconsin Resident Survey
AEI summary: http://aeinews.org/archives/465
This survey, conducted by Calumet County Citizens for Responsible Energy (CCCRE) was only informally compiled, but is still worth knowing about. Over 200 people, living from under 1000 feet to over 3000 feet from turbines, responded to the survey, about half of those in the area, and including 23 who host turbines.

Of those within 3000 feet of one or more turbines, 55% (90) felt that noise was a problem for them, while 45% (72) did not. Beyond 3000 feet, 3 of 10 said noise was bothersome, while 7 said they were not bothered. Of 33 who did not specify a distance, 15 indicated a problem with noise, while 17 said they were doing fine. Notably, 6 of the 23 respondents who host turbines said they would not do so again.

In addition:

- 30% reported negative effects on pets, farm animals, or wildlife; 70% saw no such effects
- 25% said their sleep was interrupted at least once a week; 75% had no sleep issues
- 33% reported various stress-related health issues, while two-thirds did not.
- 62% said the setbacks should be a half-mile or more; 22% supported the current 1000 foot setback.

Hoen, Wiser, Cappers, Thayer, Sethi. The Impact of Wind Power Projects on Residential Property Values in the United States: A Multi-Site Hedonic Analysis. Report funded by the Department of Energy, Lawrence Berkeley National Laboratory.
Download: http://eetd.lbl.gov/ea/ems/reports/lbnl-2829e.pdf
Detailed AEI summary: http://aeinews.org/archives/529
This detailed statistical analysis of 5000 homes sold within ten miles of wind farms finds no clear relationship between sales price and proximity to, or views of, industrial wind farms. However, close reading of the results raises some questions about trends within a mile of turbines, and the authors recommend more detailed study of the closest homes as a top priority for future research. Co-author Ryan Wiser affirmed that "It is possible that individual homes have been impacted, and frankly, I think it would be a bit silly to suggest otherwise. Human development impacts property values.[28]" Indeed, within a mile there was indeed a small (5%), but statistically insignificant, drop from the expected value of the homes.

AEI's close look at the results suggests that the apparent trend toward some property value effect largely mirrors surveys of residents near wind farms. The "problem" in interpreting this data and the surveys is that there is *not* a universal increase in annoyance or sleeplessness or dropping property values as you move closer to turbines; rather, there is an increasing *minority* of neighbors who are negatively impacted. It seems quite probable that the 5% lower *average* value found in homes within a mile is concentrated more dramatic drops in a small proportion of these properties (as, in fact, Wiser implies), suggesting that a significant minority of homes may experience a significant loss in value. *See the AEI summary linked above for far more detailed analysis of the findings of this important study*

Michael Nissenbaum preliminary results from cohort study at Mars Hill, Maine
From a letter written January 26, 2010: http://www.windaction.org/opinions/25306
Mars Hill has become well-known as a trouble spot where wind turbines atop a small ridge overlooking residential lots have caused a community-wide negative reaction to the noise. A local physician conducted interviews with residents about health effects they experienced after the wind farm went online, and this year, has expanded the study to include a cohort set of residents living out of earshot of the turbines. These results are being prepared for publication. In a recent letter, he shared the following preliminary results:

In my own work at Mars Hill, Maine, 22 out of about 33 adults who live within 3500 feet of a ridgeline arrangement of 28 1.5 megawatt wind turbines were evaluated to date, and compared with 28 people of otherwise similar age and occupation living about 3 miles away.

Here is what was found:
82% of study subjects reported new or worsened chronic sleep disturbances, versus 3% in the control group. 36% reported new chronic headaches vs 3% in the control group. 55% reported 'stress' versus none in the control group, and 82% persistent anger versus none in the people living 3 miles away. Fully a third of the study subjects had new or worsened depression, with none in the control group. 95% of the study subjects perceived reduced quality of life, versus 0% in the control group. Underlining these findings, there were 25 new prescription medications offered to the study subjects, of which 15 were accepted, compared to 4 new or increased prescriptions in the control group. The prescriptions ranged from antihypertensives and antidepressants to anti migraine medications.

Increase in Noise Levels Leads to More Annoyance Than Similar Noise in Steady State
Brown, Kamp. Response to a change in transport noise exposure: Competing explanations of change effects. J. Acoust. Soc. Am. 125 (2), February 2009
This literature review addresses an interesting question, and one that may be relevant to concerns about noise from wind farms. A long history of studies of human annoyance responses to traffic noise seems to suggest that a *change* in noise levels (for example, traffic noise increasing from 50dB to 60dB) triggers more annoyance than occurs when exposure is steady at the higher level (in this case, a steady 60dB). This paper reviews many proposed explanations for this affect; while no single explanation is identified as most likely, several common ones are shown to be unlikely, and a set of plausible explanations remains. Among the explanations that are rejected is the common assumption that the annoyance after an increase is transient, and over time will dissipate as people adapt to the new noise level; in fact, evidence suggests that annoyance remains for years after a change. Also of note is that the one study that looked closely at whether attitudes toward a noise source is related to annoyance after an increase in noise found that neither prior attitude nor changes in attitude could account for the increased annoyance. This paper and its many citations are highly recommended for anyone addressing community responses to new or increased noise sources.

Wind Turbine Syndrome book finally published
http://windturbinesyndrome.com
After over a year of fine-tuning and completion, Nina Pierpont published her much-cited — and much-reviled — book near the end of 2009. In it, she presents a "case series" of ten families near various wind farms who report a fairly consistent set of physical problems after wind farms began operation near them (mostly half mile to a mile away). She presents their stories, along with a theory that the problems may be related to low frequency noise effects on the vestibular system, perhaps largely in people with pre-existing vestibular issues. Critics suggest that the symptoms reported appear to be very rare among the tens of thousands of homes this close to wind farms, perhaps no more common around wind farms than in the population as a whole. Meanwhile, Pierpont acknowledges that these symptoms are not common, but notes that in her subjects, they began when the wind farms began operating, and generally disappeared after the families moved away (9 of the 10 families did move), and makes the case for this initial case series as evidence enough to support the next step: controlled studies to see how common such effects are, and what noise sources may (or may not) be related to the symptoms.

Sound Propagation, Wind Shear, Sound Modeling, and other Acoustics Studies

Clifford P. Schneider. Measuring background noise with an attended, mobile survey during nights with stable atmospheric conditions. Internoise 2009.
Download: http://acousticecology.org/docs/Schneider_InterNoise2009CapeVincentAmbientNoise.pdf
Detailed AEI summary: http://aeinews.org/archives/565
This study found that in one community where two new wind farms are planned, "worst case" atmospheric conditions can occur up to 30% of nights in summer and fall, peaking at over 40% of nights

in early summer. The noise models being used by wind developers in Cape Vincent, NY, predict minimal impact on neighbors thanks to an average background ambient noise level of 45dB. This study found that on nights with little wind at ground level, actual ambient sound in this rural area is generally below 35dB, and in many areas, drops to 25dB or lower for much of the night. Also, and most importantly, the study used standard predictive measures (including wind differential at two near-ground heights, daytime solar radiation, and night time cloud cover) to estimate how often the winds at turbine hub height would be high enough to turn the turbines on, even as the wind at ground level remained low – the situation that often triggers the worst night time noise complaints near wind farms. The sobering result was that such nights, which create noise issues for neighbors far beyond those predicted by the simpler noise modeling used during permitting, could be a regular occurrence for most of the summer and fall. After taking noise measurements at a wind farm currently operating in a nearby town – which found levels similar to those predicted and allowed in current Cape Vincent planning – the author notes that the vast majority of Cape Vincent homes will be close enough to hear the turbines easily on these "worst case" nights, with a third of local households likely to experience objectionable noise levels.
For this paper, we highly recommend checking out AEI's much more detailed summary at the above link

Ovenden, Shaffer, Frenando. Impact of meteorological conditions on noise propagation from freeway corridors. J. Acous. Soc. Am. 126 (1), July 2009, 25-35.
This study combined field recordings and new acoustic modeling to describe the effects of wind shear and temperature differentials on the distance over which road noise exceeds regulatory limits. The essence of this study's results is that sound may bounce off a layer boundary that is caused by wind shear or temperature layers at 30-50 meters high (a wind shear is a situation in which wind speed increases substantially with height, especially when there is a relatively sharp boundary between low and higher wind speeds). In some conditions, the researchers here found that while sound levels remain close to what traditional sound models would suggest at ranges of 200-300 meters, noise levels can actually increase at ranges of 300 meters and beyond, creating conditions in which regulatory limits are exceeded at these greater distances. In some conditions, increases occur in chaotic patterns at closer ranges, as well. The difference between traditional sound models and the results here were as high as 15-20dB, and commonly occurred at 5-10dB. It is quite possible that the turbine sound that projects down into still air near the ground during wind shear conditions is subject to these same effects; this could partially account for unusually high noise levels reported by some neighbors at certain times.

Wind Turbine Noise 2009
http://www.windturbinenoise2009.org/
This third biannual international conference produced, as usual, a wealth of papers worth knowing about. Proceedings can be purchased on DVD from the website above. Among the many papers worth hunting down online or on the proceedings disc:

Sorensen, Neilson, Villadsen, Plovsing. Implementation of the Nord2000 model for wind turbines: new possibilities for calculating noise impact.
Email author: ts@emd.dk , pn@emd.dk , jv@emd.dk

The model they introduce here is designed to address variable weather and atmospheric conditions throughout the year, as well as cumulative impacts from multiple turbines. It is claimed that this model can then predict how often, over the course of a year, a given noise level may be exceeded.

Dick Bowdler. Wind shear and its effect on noise assessment.
Email author: dick@dickbowdler.co.uk

A great assessment of wind shear patterns over the course of nine months, at five wind farms in varying terrain, collecting data every ten minutes. This is a massive amount of data (30,000 data point in all), and illuminates wind shear patterns more clearly than perhaps ever before. Wind shear is a measure of how much higher (proportionately) wind is at hub height than at ground level. Of special note is that wind shear is dramatically higher at the lowest wind speeds, though there is some at all wind speeds. Also, as expected, there is much more shear

at night than in the day, and somewhat more shear in flat than hilly areas. This paper is especially useful for its detailed graphs of measured shear distributions in various seasons, terrain, and time of day/night; these are very compelling in their ability to visually illustrate the times when turbines may kick into action when ground-level winds are low or negligible, as well as showing the range and variability of wind shear that actually occurs in each situation.

Stefan Oerlemans and Gerard Schepers. Prediction of wind turbine noise directivity and swish.
Email author: stefan@nlr.nl , schepers@ecn.nl

Fascinating field measurements of sound patterns around a turbine. Confirms some earlier studies that suggest Amplitude Modulation is highest at cross-wind directions (i.e., to the sides of the turbines), though total sound power is higher to the front and back.

Werner Richarz, Harrison Richarz. Wind turbine noise diagnostics.
Email author: werner@aercoustics.com , hricharz@gmail.com

Another illuminating study of amplitude modulation, which also finds that it is most dramatic to the sides of the turbine. The motion of the blades, in relationship to the receiver, is the key factor, not interactions between the blade and tower.

George Hessler. Using the Noise Perception Index (NPI) for assessing wind turbine noise.
Email author: George@HesslerAssociates.com

Hessler's NPI attempts to assess how often, and to what degree, turbine noise will be audible over the existing background ambient levels. Using a L90 in 10-min intervals, the NPI sets a good low threshold for background ambient. From there, the NPI assess an hourly average increase-to-ambient; Hessler particularly focuses on how often the NPI is more than 5dB (clearly perceptible),and more than 10dB (likely to lead to high levels of annoyance). In a relatively quiet setting (where ambient L90 was 21dB), the NPI was more than 5dB 56% of the time at 1000 feet, dropping to 17% of the time at 2000 feet. In more practical terms, at 2000 feet, NPI tops 10dB over 9 times in 14 days, and 5dB quite commonly, including 6-12 hours at a time every day or two, with some 3-day periods remaining under 5dB.

Hessler compares the NPI and %TA (percent of time above ambient) for wind turbines with measured L90 sound levels of 37dB and 40dB, and suggests that 37dB may be overly precautionary, and 40dB a good target. *(Note: measuring the turbines at L90 will represent the quietest times of turbine operation, though it also assures that the results are not biased by inclusion of passing transient local sounds, such as machinery or bursts of wind noise in the mic. Nonetheless, an argument might be made for using L10 to avoid these intrusions. However, since measurements are still made in 10-minute increments, there is likely not a huge difference between L90, Leq, and L10 over these short time frames.)*

Bakker, Bennett, Rapley, Thorne. Seismic effect on residents from 3MW wind turbines.
Email author: H.H.Bakker@Massey.ac.nz , davebennett@xtra.co.nz , bob@noisemeasurement.com.au

New Zealand residents near the Tarurua Range wind farms have reported noise issues at much farther distances than are commonly reported elsewhere. This study measured seismic noise using geophones at a home 2.8km from the nearest turbine. The authors note the specificity of complaint locations, and after assessing the local geology, note: "Given the Rayleigh velocity in such rocks, at frequencies of 1-10 Hz typical wavelengths will be hundreds of metres to ~1 km, with standing waves setting up nodal and antinodal points. It is possible that the residents' house, some 2 km west of the range front, is at an antinodal point in certain conditions." The recordings made here were cleansed of known extraneous low-frequency noise sources (water pump, footsteps, high wind shaking the house), revealing several periods of higher low frequency peaks that "appeared only when the wind was from a south-easterly direction, and reached a maximum intensity on those nights when the residents reported the loudest nuisance noises." The authors suggest two possible mechanisms for this noise: vibrational modes in the turbine structures, or the house generating a low-frequency resonance in response to audible sound waves. Of particular note is that, in contrast to some other studies of LF sound peaks, there was no apparent relationship between recorded sound and the rotational frequency,

blade-passing frequency or any of their harmonics.

Effects of Wind Farm Noise on Animals

Barber, Crooks, Fristrup. The costs of chronic noise exposure for terrestrial organisms. Trends in Ecology and Evolution, 2010.
Download: http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6VJ1-4X7JHPF-7&_user=10&_coverDate=09/15/2009&_rdoc=1&_fmt=&_orig=search&_sort=d&_docanchor=&view=c&_acct=C000050221&_version=1&_urlVersion=0&_userid=10&md5=d691a97788b05eb4c461d1856da41d54
Detailed AEI summary: http://aeinews.org/archives/573
This groundbreaking paper from an ongoing research project from the National Park Service Natural Sounds Program outlines the many ways that even moderate increases in human background noise can create major impacts on animals. The study proposes a new metric for use in bioacoustics research, the "effective listening area," the area over which animals can communicate with each other, or hear other animals' calls or movements. As might be expected, animals focus especially on listening for sounds at the very edges of audibility, especially faint wingbeats or footsteps of predators or prey, so that even a small increase in background noise (from a road, wind farm, or regular passing of airplanes) can drown out sounds that need to be heard. The authors note that analyses of transportation noise impacts often assert that a 3dB increase in noise – a barely perceptual change – has "negligible" effects, whereas in fact this increased noise reduces the listening area of animals by 30%. A 10dB increase in background noise (likely within a few hundred meters of a road or wind farm, or as a private plane passes nearby) reduces listening area by 90%.

In addition to introducing this important new metric, the paper provides a good overview of previous research that has addressed the impacts of moderate noise on various animals, including bats, antelope, squirrels, and birds.

Baerwald, Edworthy, Holder, Barclay. A Large-scale Mitigation Experiment to Reduce Bat Fatalities at Wind Energy Facilities. Journal of Wildlife Management 73(7), 1077-1081.
Email author: erin.baerwald@ucalgary.ca
Though this paper does not address acoustics issues, it's of interest here because of its examination of the economic impact of slightly increasing the cut-in speed for wind turbines, which could be a useful operational adjustment in some areas during times of extremely still air at ground level. In this study, the goal was reducing bat mortality (which is caused as bats fly through the low-pressure areas around turbine blades and suffer catastrophic expansions of their lungs or other tissues). Since bats do not fly in high winds, the researchers experimented with increasing the turbine cut-in speed (the point at which the turbines turn on) to 5.5m/s, rather than their normal 4m/s. While this reduced the total time that the turbines were on and generating electricity by 42%, the declines in total electricity generated and total revenue were far less, since the most-productive higher wind times were not interrupted. Lost revenue was only $200-275 per turbine over the course of the month. In addition, due to technical limitations, the 15 turbines being used for the test had to have their cut-in speeds changed for the entire month; if such changes were made only at night, costs would be even less.

Pearce-Higgins, Stephen, Langston, Bainbridge, Bullman. The distribution of breeding birds around upland wind farms. Journal of Applied Ecology, doi: 10.1111/j.1365-2664.2009.01715.x
Email author: james.pearce-higgins@rspb.org.uk
See abstract: http://www3.interscience.wiley.com/journal/122608445/abstract
AEI summary: http://aeinews.org/archives/406
This comprehensive survey of breeding birds in non-agricultural British uplands (moors and grassland) included weekly surveys during the breeding season at 12 different wind farm sites, along with comparable nearby landscapes without turbines. Half the wind farms were from the previous generation (WAY back in the '90s), with hub heights of 40m and less; the other half had hub heights of 60-70m. Of the twelve species that were observed often enough to provide good data, five seemed relatively unaffected by turbines (including kestrel, lapwing, grouse, skylark, and stonechat), while 7 species were less likely to nest within 500m of turbines, with smaller (i.e., not statistically significant) effects extending to 800m, or roughly half a mile. For six of the species (buzzard, hen harrier, plover,

snipe, curlew, and wheatear), numbers were reduced by 39-52%.

The authors note that there is a pressing need for examination of the reasons for the depressed numbers: "we do not know whether our observations of avoidance of turbines reflect a behavioural displacement, the local population consequences of collision mortality or reduced productivity, or both. The distinction is important. If there is high mortality of birds breeding close to the turbines associated with collision *(ed. note: or reduced breeding productivity)*, then a wind farm may become a population sink if repeatedly colonized by naive birds. If, however, the birds simply avoid breeding close to the turbines, then…displaced birds may settle elsewhere with little cost." They also note that "Whether wind farms result in meaningful population-level effects at a regional and national scale depends both upon the mechanisms involved, and the overlap between bird distribution and wind farm development," and they encourage new development to avoid high densities of open country species, until these factors can be more clearly understood.

They note the contrast between these findings and those of Devereux et al, 2008 *(Ed. note: The earlier study looked at wintering birds in farmland, rather than breeding birds in uplands, and found little effect at any distance from turbines.)* and suggest that "species occupying remote semi-natural habitats may be more sensitive to wind farm development than species occupying intensive production landscapes."

Offshore wind farms: impact area on porpoises is small during operation, but potentially over 20km during construction

These two papers, from related research teams, assessed the impacts of construction and operation of wind farms in Europe on local populations of harbor porpoises and harbor seals.

Tougaard, Henriksen, Miller. Underwater noise from three types of offshore wind turbines: Estimation of impact zones for harbor porpoises and harbor seals. J. Acoust. Soc. Am. 125 (6), June 2009. 3766-3773

Underwater noise was recorded from three different types of wind turbines in Denmark and Sweden. The authors note that virtually all airborne noise from the turbine blades is reflected off the surface of the water, while vibrations from the machinery are transmitted through the tower and into the foundation, from where it radiates out into the water column and seabed. In general, turbine noise was only measurable above ambient noise at frequencies below 500Hz, with total SPLs of 109-127db re 1uPa rms, measured at 14-20m from the turbines' foundations. *(Note: underwater sound measurements do not equate with airborne sound: these levels would sound similar to 46-64dB in air, with natural ocean ambient sound generally ranging from 45-90dB, depending on weather and animal sounds nearby)* By comparing measured sound levels with audiograms of harbor seals and harbor porpoises, the researchers determined that the sounds were only slightly audible for the porpoises at ranges of 20-70m, whereas harbor seals may hear the sounds at ranges of 100m to several kilometers. As a bottom line, researchers suggest that behavioral changes are very unlikely in harbor porpoises except at very close ranges, while seals may have some behavioral reaction out to a few hundred meters. For both species, masking of communication calls is predicted here to be low to non-existent (due to differences between vocalization frequency patterns and the predominantly low-frequency turbine noise), and the sound is too low to cause physical injury, no matter how close the animals are.

Tougaard, Carstensen, Teilmann, Skov, Rasmussun. Pile driving zone of responsiveness extends beyond 20km for harbor porpoises (Phocoena phocoena (L.)) (L). J.Acous.Soc.Am. 126(1), July 2009, 11-14.

This study took place during construction of an offshore wind farm in the North Sea. Recorders were placed in the wind farm and in two locations outside the wind farm, at 7 and 20km away. During pile driving operations, which generate high-intensity impulsive sounds (235dB peak-peak), detections of harbour porpoises declined at all listening stations. (The baseline was detections during construction, but without pile driving activity taking place) The declines were not dramatic (within the 95% confidence bars in most cases, barely beyond them in some cases), but were consistently found. There was no clear difference in detection rates at 7 and 20km, which implies that the displacement effect extends well beyond 20km. The differences inside the wind farm were minimal when pile driving was

occurring, though total detections were lower inside the farm than outside at all times, suggesting that animals inside the construction zone were individuals who were more acclimated or tolerant of the ongoing construction noise.

Also of special note, from 2008:
Evans, P.G., Ed. **ASCOBANS/ECS Workshop: Offshore Wind Farms and Marine Mammals: Impacts and Methodologies for Assessing Impacts**. ECS Special Publication Series No. 49, February 2008. 70pp.
Download:
http://www.seawatchfoundation.org.uk/docs/7.%20ECS%20proceeding%20workshop%20windfarm%20and%20marine%20mammals%202008.pdf
AEI summary: about halfway down on this page: http://acousticecology.org/scienceresearch2008.html
Includes many papers of interest investigating marine mammal behavior around European offshore wind farms.

Social Considerations

As I've gotten deeper into exploring the issues surrounding wind farm noise, it's become clear that there are two centrally important yet distinct social factors at play. The first has to do with social dynamics within rural communities, and how this affects people's willingness or desire to talk freely about what they're experiencing. On a larger scale, our society as a whole is facing a decision about where we draw the line as we try to balance our need for carbon-neutral energy with consideration for the impacts of industrial development on rural residents. This report is not the place to fully address the richness and complexities inherent in these social dynamics, but they're important to mention and keep in mind as we wrestle with the acoustics and policy questions.

Local social dynamics and reticence to complain

Many rural residents speak frankly about the social tensions that result when some people speak negatively about their experiences with noise from turbines on the property of friends, neighbors, and even relatives. A Wisconsin farmer, bound by a gag order in his lease, had this to say in an anonymous interview[29]: "Now, at social functions, we can clearly see the huge division this has created among community members. Suddenly, there are strong-sided discussions and heated words between friends and, yes, between relatives[30] about wind turbines. Perhaps this is a greater consequence than the harm caused to my land — life is short, and friendships are precious." A resident in North Dakota[31] reports a similar feeling: "(At a Christmas party,) I brought up wind turbines, and the room just went silent. There are lifelong friends who won't even talk to each other."

In many rural communities, economic factors affect people's willingness to speak up. In Wisconsin, I heard about building contractors and small business owners who, though bothered by noise, didn't want to alienate customers, so refrained from working with neighbors that were dealing with the wind farm developers about noise issues[32]. For most farmers who host wind turbines, the moderate annoyance caused by noise is more than made up for by the additional income from lease payments (which may be necessary to make ends meet). While some wind farms offer non-participating neighbors smaller annual payments, in acknowledgement of the disruption caused by the noise, this is an exception rather than the rule, and some who have been offered such recompense have refused it, either on principle, or because they don't want to agree to accompanying gag orders against speaking about their experiences.

In Vinalhaven, Maine, the economics of speaking up have an unusual element, though one that may become more common as communities move toward becoming partners in wind farms for various reasons[33]. Vinalhaven is an island off the coast; purchasing electricity from the mainland is exceedingly expensive, so a collaborative project of a regional non-profit and the local electricity co-op led to the construction of three turbines, which will generate most of the electricity needed by the 2000 residents. The community project generated a lot of local excitement and support, so when the turbines began operating and several neighbors within a half-mile were shocked at the noise they heard, it triggered several unique situations in response. The small LLC that was formed to build the wind farm is treating the noise as a community issue, rather than viewing the affected neighbors as bothersome cranks (as is unfortunately common when dealing with a distant wind developer); in Vinalhaven, investigations are under way to see whether there are specific wind and atmospheric conditions that correspond to the times when neighbors are most disturbed. This is a very constructive and positive approach; however, a new twist is added by the fact that any adjustments made to operations — any reductions in turbine speed, or times when the turbines are shut down — will lead directly to increased electric rates for everyone served by the electic co-op. Rather than facing the ire of a few landowners leasing to the wind farm, those who speak up about noise issues in Vinalhaven will be literally costing all their neighbors money out of pocket. Unsurprisingly, while some neighbors are actively speaking out and are collaborating with the wind LLC to try to learn more about the source of the noise issues, there are others within a half-mile to mile who admit privately that they are bothered by the noise, but have chosen not to publicly complain[34].

Larger social decisions about public benefit vs. individual costs

An entirely different "tough nut to crack" becomes apparent as soon as we acknowledge that wind farms make enough noise to often be audible above background sound levels out to a half-mile or mile (most current noise limits and sound models, which call for nighttime turbine noise of 40-50dB at 1000 to 2000 feet are, in practice, affirming that it will be at least somewhat audible to a mile when ambient noise is low). As will be fleshed out in the next section of this report, despite the fact that the noise is moderate (by modern suburban noise standards), or that most people are not bothered, there can be a significant minority of neighbors who are fairly dramatically affected, especially by sleep disruption.

While most of us would agree that we can't set the threshold for disturbance too low (if one person in a thousand is affected, few would advocate banning an activity), it is far harder to come to consensus on how much disruption is too much. Does our need for carbon-neutral electricity justify causing some significant disruption to 5% of those within a mile? Many would say yes. But then, how many would think that it's acceptable to create ongoing annoyance or sleep disruption in 20% of neighbors? Some will feel this is alright, but an increasing number of others would feel the scales were tipping too far. And very few would want half the locals to be negatively impacted. This is exactly the sort of social conversation we should be having; we are, in effect, already making decisions such as this, but without acknowledging that we are consigning a minority of the population to some degree of suffering, in order to move forward with wind energy.

There is of course no way to reliably quantify the degree of disruption being caused by wind farm noise; the reactions are subjective and variable, and the practical impact of these effects are difficult to define (e.g., how much sleep disruption per month can we tolerate before it causes clear physiological symptoms such as increased stress hormones in our bloodstream, or psychological impacts such as lack of concentration?).

At the extreme end of the scale, some people are driven from their homes by the ways that the noise disrupted their lives. Others can't leave, but suffer from regularly depleted sleep, and a litany of well-understood side-effects of sleep deprivation. Many experience sleep or other physical problems (uncomfortable pressure waves, ear sensations, etc.) periodically during most weeks. Some find that they no longer can enjoy being in their gardens regularly, or that their sleep is interrupted several times a month in particular wind conditions. Many are generally not bothered, but occasionally find themselves waking up or noticing that the noise is louder than normal during the day. Where along this scale might we draw the line?

Resolving the Science/Experience Paradox

At this point, it may not surprise you to hear that when I began thinking about writing this report, the central theme I had in mind was the paradoxes that have become apparent to everyone who looks deeply at the issue of wind farm noise. Some of these are apparent in the information presented above: most obviously, in the simultaneous presence of reports of severely disturbing noise problems and the fact that most wind farms trigger few if any noise complaints.

Likewise, it's striking to read the reassuring results of various large-scale studies that have investigated the measurable effects of living near wind turbines (including annoyance, health impacts, and property values), which nearly always find no clear correlation[35], while also trying to make sense of the increasingly widespread reports of all of these effects actually occurring around wind farms. As I've worked to integrate the disparate evidence presented to date, including looking closely at the raw data presented in the studies finding no "statistically significant" correlations, some potentially unifying threads have begun to appear in the data, interpretations, and reports of neighbors.

I've come to the conclusion that the apparent paradox of the gulf between reassuring research results and the life-changing impacts reported by neighbors can be resolved by acknowledging a simple pattern: while the majority of those exposed to wind farm noise are relatively unaffected, a significant minority experiences at times dramatic impacts. This appears to hold true in annoyance, health effects, and property values. Since only a minority is affected, no clear trends appear in which effects become worse as you get closer; especially, when very close, there is no dramatic increase in impacts, and without this sort of clear "anchor" for the data trends, no "dose-response" relationship is likely to be found.

While this "simple pattern" may seem to be a fairly common-sense insight, it has not been widely recognized because each side in the increasingly contentious debate tends to ignore one aspect of the pattern. Industry representatives do their best to downplay, disregard, or distort the nature of complaints (most egregiously, by assuming that all noise complaints are merely a ruse by those opposed to wind farms). Meanwhile, community noise activists focus on repeating the stories of those who are negatively affected, while ignoring or being unaware of the many more people around each wind farm who are not particularly bothered by the noise[36].

Three formal scientific studies are good examples of the research side of the paradox, and its resolution; all of these studies are noted in the Recent Research section, and I encourage you to seek out the detailed summaries and links to the source material on AEI's website[37].

The first two are the most recent papers top come out of a series of surveys of residents near wind farms in Scandinavia, including some in rural areas and some in more suburban areas. The ongoing work by Eja Pederson and Kirsten Persson Waye provides a slew of fascinating insights into the range of responses from a large a population of people (over 1800 total) living near wind farms. Several pieces of the data jump out:

- As noise levels increased, Pederson found a steadily increasing minority of rural residents who were "very" or "somewhat" annoyed by wind turbine noise, with a dramatic increase above 40dB: 10% at 30-35dB, 16-20% at 35-40dB, and 25-45% at 40dB and above.
- People in suburban areas, where the other ambient noises were higher, were much less annoyed by wind turbine sound at all dB levels (kicking in at 5% at 35-40dB and topping out at just 10% at over 40dB).
- Waye found that when the noise had a dominant "swishing" component, 45% were "rather" or "very" annoyed when sound levels were only 35-40dB. Even at only 30-35dB, over 20% were similarly annoyed.
- Waye also provides the key insight that helps explain the lack of overall trend toward higher annoyance: in addition to those reporting various degrees of annoyance at each sound level, another 40-70% of the population could *hear* the turbines, but did not report annoyance. For example, at 30-35dB, over half of rural residents reported hearing the turbines, while only 8-

12% were annoyed; at 35-40dB (within most global regulatory limits), 85% heard them, while just under 20% were annoyed; and at 40-45dB (within common US regulatory limits), 95% heard them, while 45% were annoyed.

Dr. Robert McMurtry, a former dean of medicine at the University of Western Ontario, was quoted in a recent article in Macleans[38] that "When I first read about the side effects I thought that they didn't sound very convincing. But then I did my homework, and I became alarmed." Based on surveys he has done, and others in Europe, McMurtry estimates that 25 per cent of people living within 2.5 km (1.5 miles) of turbines experience disruptions in their daily lives, especially sleep disturbances, which often balloon into other health problems. He thinks that there are enough problems in wind farms worldwide to justify a serious epidemiological look at the industry. "You can assume that all these people are liars," says McMurtry. "But many of these folks will tell you that they welcome wind turbines. They just want someone to turn them off at night, or move them further back."

The third study that suggests that these trends may apply to more than just annoyance is the Department of Energy's property values study. This study, too, found no clear correlation with distance from or visibility of wind farms. The form of statistical analysis used to analyze the sales of 5000 homes sold within ten miles of wind farms has garnered some criticism[39], but I am not savvy enough with statistical techniques to know whether such criticism is warranted. However, a close look at the data reveals that there are some indications of a trend toward homes being sold at less than expected prices among the closest homes considered.

To assess whether nuisance factors affected home prices, the researchers compared sales within a mile of turbines to sales five miles or more from turbines. Their distance classifications included 0-3000 feet, 3000-5280 feet, 1-3 miles, 3-5 miles, and over 5 miles. While all zones beyond a mile showed virtually no differences in sales prices, both of the classes under a mile had modest 5% declines in value (interestingly, the decline was slightly more extreme between 3000 feet and a mile). However, there were not enough sales of homes this close (125 under a mile, compared to roughly 4000 at 1-5 miles, and 870 beyond 5 miles) to provide statistical significance; that is, the margin of error is greater than the 5% change found, which means that with a larger number of sales, the average change in value might move to zero (or, just as likely, to -10%). Despite the limitations of the small sample size, it is striking to look at the data charts presented in the paper, and to see that of all the wind farm-related factors that were being considered, *only* proximity nudged the values away from the baseline average. In the context of the rest of the findings, the change co-efficients for proximity (minus.05 and .06) actually jump out of the data.

When considered in consort with surveys that suggest that only a minority of those close to wind farms experience especially problematic noise conditions (and remembering that many wind farms have little in the way of noise issues at all), it seems reasonable to suggest that the average decline of 5% in home values may be concentrated in a smaller number of homes that lost considerable value. While this level of raw data is not available in the final report, the authors do recommend that more detailed study of the closest homes is a top priority for future research.

There have certainly been some instances of dramatic decreases in value, and even marketability, of homes near wind farms. In a few cases, wind developers have bought homes from people who could not live with the noise (and apparently could not easily sell on their own). Even one of the authors of the DOE study acknowledged[40] "It is possible that individual homes have been impacted, and frankly, I think it would be a bit silly to suggest otherwise. Human development impacts property values."

How to account for this pattern of a significant minority being dramatically affected?

A complex combination of factors probably contributes to this trend toward a significant minority of people being more affected. Among the possible contributing factors:

- Some may be project-specific, contributing to a cluster of higher annoyance at a given wind

farm: for example, malfunctioning turbines or manufacturing defects may create higher noise levels in rare instances. Or, there may be an above-average number homes downwind (or cross-wind, where amplitude modulation is worse) from turbines, increasing the percentage of problem sites. Similarly, some areas may be more prone to the "worst-case" atmospheric conditions of nearly no wind at the ground, while winds trigger turbines into action; in these situations, night time noise can be far above the natural ambient levels, and may also contribute to absolute noise levels at nearby homes that exceed expected (and permitted) maximums.

- An obvious — and perhaps the most important — factor is the well-studied individual variability in sensitivity to noise. Among any population, and for any noise source, acoustics researchers have long known that some people are more sensitive to being disturbed by noise, exhibiting increased annoyance, more sleep disruption, and even more physiological reactions to noise than most other people. While the simplicity of this observation leads it to be overlooked, the fact is that we need to acknowledge these individual differences, rather than assuming that the average or majority response is all we should consider. These differences have been studied for decades, and there are many factors that seem to contribute. Among these is one's attitude toward the sound source, though many studies have confirmed that this is not a determining factor, but simply a contributing factor for some individuals. While there is often a correlation, there is no evidence of a causal relationship; that is, such factors can explain some of the reported annoyance, but far from all, despite the eagerness of industry spokesmen to attribute noise complaints entirely to negative attitudes. Some increased sensitivity to noise is age-related; for example, sleep arousals (non-waking disruptions in normal sleep cycles) increase with age[41]. Personality plays a part, as do physiological differences, and previous exposures to noise (especially disturbing or damaging noise). But as the Minnesota Department of Health report affirmed[42], differences in reactions generally have little relationship to will or intent. There is also some evidence that noise-sensitive individuals may be at higher risk of developing cardiovascular disease, perhaps due to increased waking and arousal disrupting their sleep[43].

- Another factor that seems to be a likely contributor is the density of homes within and around the wind farm. I have not seen any studies looking at this, but it seems plausible that the vast majority of wind farms trigger no groundswell of noise complaints because they are not affecting as many people in total. Certainly, most of the wind farms that have triggered community reactions are in places where many homes are close by. Often, dozens of homes are within a half-mile or mile of one or more turbines; within this large population, it's not surprising that a few will be severely affected. Once some neighbors start talking about the issue, it creates local support for voicing concerns (which can at least partially counter the previously-mentioned reticence to make waves in a small community). If a wind farm is only audible to a few homes, and only one or two are having troubles, they are more likely to feel that they should just put up with it.

Looking Ahead: 2010 and Beyond

While much of the time and attention devoted to wind farm noise is spent looking back at specific troubling experiences, there is of course a steady stream of ongoing developments and new themes coming along. Here are some of the key topics likely to be spurring discussion in 2010 and beyond:

Offshore wind

Both the industry and state and federal governments are working hard to move the offshore wind industry into higher gear[44]. Offshore wind has several advantages, including steadier and higher velocity winds, and proximity to population centers. Concerns include the known effects of construction noise and possible effects of electromagnetic fields in transmission cables on marine life[45], and disruptions to commercial fishermen and lobstermen. More recently, the Department of Homeland Security raised concerns about offshore wind farms causing radar interference, and is looking into solutions[46].

While offshore wind farms are more common in Europe, things are moving slowly here in the U.S., with the drawn-out controversy over Cape Wind off Martha's Vineyard getting the most attention. Meanwhile, though, states all along the eastern seaboard are moving aggressively to encourage offshore wind[47], and the Great Lakes region is also the site of many new proposals. The current generation of turbines need to be built in shallow water, with foundations in the seabed much like those used on land; these sites are generating predictable resistance from those who don't want to see turbines, and others concerned about navigation and the fishing industry. There are some early indications that at least in some situations, airborne noise issues may occur at greater distances than are commonly heard on land[48]; though of course waves mask the sounds right along the coast, these ambient sounds diminish within a short distance of the shoreline.

The real future for offshore wind — and arguably, for wind energy as a substantial contributor to our energy mix — lies in floating deepwater turbines. Out of sight, out of earshot, and away from more coastal recreational boating and fishing areas, floating turbines will also access even higher winds. Additionally, construction noise will be far less of a factor. The first field test of a floating turbine is currently underway in Norway[49], and the states of Maine and Massachusetts are moving forward with plans to test several designs of floating turbines in the next couple of years[50]. Maine, in particular, is committed to far-offshore wind; they have decided to solve the deep-water engineering challenges rather than face the near-shore political challenges that have held up Cape Wind for so long.

AEI is convinced that a decade from now, our current focus on finding places to fit 1-2 megawatt turbines in amongst farm and residential areas will seem downright silly, as 5-10 megawatt turbines come online as part of widespread far offshore wind farm developments.

Marine Spatial Planning / Regional Alternative Energy Planning

Of all the topics we'll be hearing about this year, spatial planning is the most exciting to me, because it holds the promise of allowing the wind industry to expand with less local and environmental resistance, by being part of a coherent regional and national landscape-scale plan. The idea is related to zoning, but more flexible: bring together biologists, regulators, industry, and environmentalists to take a big-picture look at the landscape (both dry land and oceanic), identifying the areas with solid wind resources, areas where undisturbed habitat is essential, and areas where other human activities are taking place (other industrial development, recreational areas, residential areas, military ranges, etc.). From here, the goal is to identify places to concentrate wind and other development so that it will encounter minimal conflicts with other land uses.

On land, The Nature Conservancy has created maps to guide conservation-sensitive wind planning in Kansas, Colorado, Montana, and Oklahoma, and in mid-2009 received a grant from the American Wind and Wildlife Institute, a coalition of industry and environmental organizations, to create a nationwide

wind and wildlife resource map[51]. In the UK, the Royal Society for the Preservation of Birds, along with Scottish Natural Heritage, has initiated a similar project, centered on the production of a Bird Sensitivity Map for use in planning wind farms in Scotland[52].

Offshore, the Obama administration's new ocean policy is highlighting the value of Marine Spatial Planning[53]. Offshore renewable energy development is likely to be shaped by this process, which is just getting underway now with initial gathering of information on current uses and biological hot spots.

And from the corporate side of the table, the World Ocean Council, a "global, cross-sectoral industry leadership alliance on ocean sustainability and stewardship," is planning a Sustainable Ocean Summit in June 2010, where renewable energy companies will join with other ocean industries to promote Corporate Ocean Responsibility, including Marine Spatial Planning[54].

State and Provincial Siting Regulations in the Pipeline

During 2010, we're likely to see new wind farm siting regulations announced in two key states where there has been significant concern about the proximity of wind farms to many homes: Wisconsin and Minnesota. In Wisconsin, the state legislature passed a bill in early 2009 that established state regulatory authority over wind farm siting, after several local governments adopted larger setbacks than the industry was ready to accept. The Wisconsin Public Regulatory Commission is working on the statewide standards, which should be released in 2010. In Minnesota, noise concerns prompted the state Public Utilities Commission to initiate an review of its setback standards[55], and to commission a report on the health effects of wind farms, which noted that noise "generally is not a major concern for humans beyond a half-mile or so," while recommending that state setbacks be at least 1000 feet. In January 2010, the PUC held a hearing on siting, after which several commissioners indicated that the Commission is not likely to jump to any quick conclusions. "I think there are a lot of remaining unanswered questions. I think there are a lot of…substantive questions as well," Commissioner Phyllis Reha said. "I think the commission has a lot of work to do before we make any kinds of decisions."[56]

In Ontario, the new Green Energy Act may have hit a sweet spot, as it has triggered vehement complaints from both the industry and from residents[57]. It sets a minimum 550m (1800 feet) setback from homes, increasing to 950m (3100 feet) when they are louder, and 1500m (just under a mile) for large wind farms; the latter two standards seem excessive to the industry, and the first two are not large enough for some residents. The Act has been challenged in court by a resident who contends that the five turbines due to be erected within 900 meters of his house is too many, too close[58].

Canada is also ground zero for challenges to the industry's conventional wisdom that property values are not affected by new wind farms. In late 2008, residents on Prince Edward Island had their property values downgraded to the same as "industrial areas" after a wind farm was constructed nearby[59]; and in Ontario this year, a resident had his house valuation cut in half thanks to noise from a transformer at a wind farm[60] (it's important to note that this sound is 24/7, and is not the same as sound from turbines).

Health Effects Studies

Several studies are underway, each designed to take the next steps in providing a clearer, and more scientifically sound, picture of whether the noise of wind farms can lead to any significant health effects. Some may be completed in 2010, though others will likely take longer.

- Two initiatives are underway in Ontario. First is a before-and-after survey of residents on Wolfe Island[61], where an 86-turbine wind farm began operation in June, with turbines as close as 400m (about a quarter mile) from homes. This is the first such large-scale assessment of self-reported health issues that includes a clear baseline before the wind farm began operating. Second, the provincial Green Energy Act provides for the establishment and funding of an academic research chair to keep on top of the latest science and technology associated

with renewable energy projects, especially wind turbines. According to a Ministry of the Environment spokesperson[62], "That chair's role will be to research potential public health effects of renewable energy projects as new information and new science emerges. That will ensure that our approvals continue to be protective of public health and the environment. That work will be ongoing." Details on this new chair should be forthcoming in 2010.

- The Japanese Environment Ministry is currently gearing up for the April launch of a nationwide field survey around all 1500 wind turbines in operation in the country[63]. Prompted by health complaints near 30 of the country's 376 wind farms (1-20 turbines each), the survey will the first such comprehensive study of the question; low frequency and audible noise will be recorded, to see whether there is any correlation between these sounds and the reported effects.

- And, in Maine, Dr. Michael Nissenbaum is completing a cohort study that expands on his initial post-construction health-effects study at Mars Hill. See more details on this work above, in the Recent Research section, on page 14-15.

A few other things to keep an ear out for

Three other things appear to be worth watching for in 2010 and beyond:

- Several independent acousticians are doing detailed investigations of low-frequency noise in homes where residents have reported issues[64]. In the US, some early indications suggest that infrasound in the 5Hz range can include very extreme amplitude modulation (20-40dB), within the same 1-2 seconds that audible AM is heard, and peaking at levels not far below what is considered perceptible by the most sensitive individuals. And in New Zealand, acousticians report somewhat similar pulsed sounds at 2-10Hz. It remains to be seen what of consequence will emerge from these still-preliminary studies, but they could well be of interest as the data is more fully analyzed and made public.

- A hot new topic in industry communications in recent months is the "nocebo effect[65]," which is touted as being responsible for many of the hotbeds of noise complaints. The idea is that the *expectation* that noise will be bothersome can *create* an annoyance reaction. Within the acoustics field, there is some research that is similar to this idea; specifically, it appears that very low frequency sound becomes more noticeable once an individual tries to listen for it, and indeed, once it is noticed, is very hard to ignore[66]. Like many of the other factors that are sometimes put forward as explaining all the noise complaints (including negative attitudes toward wind farms and distrust of developers), it is likely that the drumbeat of negative stories about wind noise may contribute to some people paying close enough attention to be bothered; but similarly, it is surely over-reaching to paint with too broad a nocebo brush, and assume that the sound is really inaudible or easily tolerable, and only the negative expectation creates the problem. Nonetheless, expect to hear more of this word in the months and years to come.

- Many citizen groups, and some wind farm operators, have begun suggesting that some noise issues in existing wind farms may be mitigated by adopting some changes to wind farm operational procedures. This is still an emerging idea, especially for larger wind farm companies, but expect to hear more discussion of some of these possibilties in the coming year. As noted above, the small company operating Fox Island Wind Farm in Vinalhaven, Maine, is actively seeking the information that could help them identify times when slowing or shutting of the turbines could minimize the current noise issues some neighbors are experiencing. Changes in cut-in speeds, rotational speed, and "feathering" of the blades are all things that could reduce sound impacts when necessary. A recent study aimed at reducing bat mortality (see Recent Science section, page 18) found that slightly increasing the speed at which turbines turn on can reduce the total operating time significantly, while having a minimal effect on total revenues; this could be a promising approach for dealing with noise

during quiet evenings when speeds at hub height are still moderate, but enough to trigger turbines into action.

- Finally, an interesting tidbit popped up in the past couple weeks. At a presentation at an Institute of Acoustics symposium on wind farm noise in Wales, Daryoush Allaei, a Minnesota-based noise control engineer stressed that as wind turbines age, more noise and vibration will result, due to blade mistuning, misalignment, imbalance, resonance, fastener looseness, and damages and defects in bearings and tower structure. He notes that maintenance is often put off for budgetary reasons, but that diligent monitoring and maintenance will be a key to minimizing noise problems around wind farms as they age.

Resources

Fed Wind Siting Information Center
http://www1.eere.energy.gov/windandhydro/federalwindsiting/index.html
Features links to federal wind-related Environmental Impact Statements, information and links for various agency wind initiatives (BLM, USFS, FWS, FAA, DHS, etc), and a "don't worry be happy" guide for county commissioners (noise info is entirely based on industry "facts/myths" publications).

North American Windpower
http://nawindpower.comre
Trade magazine and website that includes good coverage of community-relations issues, as well as the full range of technical and policy developments.

Renewable Energy World
http://www.renewableenergyworld.com
Another trade magazine and website with lots of good information

Windustry.org
http://www.windustry.org/GLRWEI
Presentations from conference and webinars for those considering leasing land for wind energy
Windustry is focused on community wind projects, including information on small home- and farm-scale wind

For links to government agency sites, country-scale trade organizations (American, Canadian, German, UK etc. wind energy associations), and local community advocacy groups raising questions about wind farm noise issues, see the more complete resources listing at the end of AEI's initial Special Report on wind farm noise: http://acousticecology.org/srwind.html#Anchor-3800

For older scientific studies that are of continuing importance in understanding wind farm noise issues, see the annotated list in AEI's Special Report at http://acousticecology.org/srwind.html#Anchor-14210

About the Acoustic Ecology Institute

The Acoustic Ecology Institute was incorporated as a 501(c)3 organization in 2004. Since then, AEI has developed a reputation as an honest broker of information and resources regarding sound-related environmental issues. Generally steering clear of advocacy-oriented activities, AEI focuses on providing clear information on science and policy issues via a news digest, lay summaries of new research, and a series of comprehensive special reports on key topics, all available free of charge at http://AcousticEcology.org and http://AEInews.org. Our work on ocean noise issues has garnered enthusiastic responses from top agency staff and field researchers, journalists, NGOs, Navy staff, and oil and gas industry managers.

AEI is primarily the work of Jim Cummings, a writer and editor who has covered environmental, science, and socially responsible investing topics since the early 1980s. He was an invited plenary speaker at the Alberta oil and gas noise control conference in 2007 and 2009, and an invited participant and presenter for the Canadian Department of Fisheries and Oceans expert committee on Seismic Survey Mitigation Effectiveness in 2009. In 2007, he was the guest editor of a special double issue on Ocean Noise for the *Journal of International Wildlife Law and Policy*.

For more on AEI, see http://acousticecology.org/press/index.html
AEI's Special Reports: http://AcousticEcology.org/specialreports.html
AEI's news and science feed: http://AEInews.org
AEI's archive and ongoing coverage of wind-related topics:
http://aeinews.org/archives/category/wind-turbines

Footnotes

[1] See AEI's annual Ocean Noise recaps at http://AcousticEcology.org/specialreports.html
[2] Quote from Sally Wylie, Vinalhaven, Maine. http://www.workingwaterfront.com/online-exclusives/Opinion/13571/
[3] Figures drawn from Wind Energy Market 2009, German Wind Energy Association. Measurements here include sound output at wind speeds of 6-9m/s (13-20mph), which represent the highest sound levels likely to be produced.
[4] 100dB equivalences also noted as the sound inside a subway train or alongside a rail line. For some decibel charts, see http://umlan.com/img/reviews/h102/cooler_decibel_chart.jpg , http://raider.muc.edu/~miskeljp/ds/resources/decibel_chart.gif , http://www.osha.gov/dts/osta/otm/noise/images/common_sounds.gif , http://downloads.cas.psu.edu/4H/SoundDecibelChart.pdf , http://www.makeitlouder.com/Decibel%20Level%20Chart.txt
[5] Among the sites that provide fairly comprehensive, if predominantly critical, news archives of noise issues are http://windwatch.org and http://wind-action.org
Several locally-oriented sites also include lots of filtered coverage of events elsewhere, notably http://www.batr.net/cohoctonwindwatch/ , http://windconcernsontario.wordpress.com/ , and http://betterplan.squarespace.com/
Google searches on a given wind farm name and the words *turbine* and *noise* also work well.
[6] See http://aeinews.org/archives/277 for summary of and link to sleep arousal report by Dr. Christopher Hanning
[7] See http://aeinews.org/archives/350 Initial reports of six houses purchased; company affirms two were bought from neighbors who could not live with the noise
[8] See this news report of real estate agent refusing to list the Davis home: http://www.spaldingtoday.co.uk/news/Home-near-turbines-won39t-sell.4105560.jp
[9] Personal communication, source confidential at this point, as work is still being prepared for publication.
[10] For example, some of the Mars Hill homes, and several homes abandoned due to noise issues, are in the range of 3000 feet from the nearest turbines.
[11] See this news report of real estate agent refusing to list the Davis home: http://www.spaldingtoday.co.uk/news/Home-near-turbines-won39t-sell.4105560.jp
And this related document from the Davis' local assessment office, changing the tax status of the property: http://info.valuation-tribunals.gov.uk/decision_document.asp?appeal=/decision_documents/documents/ct_england/2525475651032c.htm
[12] This statement ("a dozen or so") is based on searching for news articles related to wind turbine noise problems at two key wind activist websites that archive news reports, Wind Action (http://windaction.org) and National Wind Watch (http://wind-watch.org), as well as Google searches focusing on many wind farms whose names did not ring a bell from my work over the past 18 months tracking these issues.
[13] Information on new wind farms online came from annual and quarterly reports of the American Wind Energy Association, available at http://www.awea.org/reports/
[14] I did not find a source for total number of wind farms; this figure assumes that the average size of wind farms installed in 2008 and 2009 (in MW) is relatively similar to that of earlier installed wind farms. It is possible, perhaps likely, that earlier wind farms tended to be smaller, and so there may be more than 400 operating wind farms.
[15] See footnote 6
[16] See this AWEA page on which you can click on each state and get a list of all active wind farms in that state, with total MW and numbers of turbines listed. Try it for your state and see how many you've heard complaints from: http://www.awea.org/projects/
[17] Again, based on tracking these issues for 18 months, and searches at the sites mentioned in footnote 6. I did not do a comprehensive search of all wind farms, due to time constraints; rather, I checked any wind farms that rang a bell from earlier reading, plus other wind farms in states where known noise issues had arisen (i.e., states with already active citizen groups addressing noise issues, where it is more likely that new complaints would arise), and all ten of the largest wind farms. A more comprehensive study of reported noise

issues at all wind farms would be beneficial, to help clarify if there are particular situations (e.g., population density within a half-mile or within a mile) that seem to spur more complaints.

[18] Taking at face value a statement quoted in http://www.wind-watch.org/news/2008/08/12/landowner-insists-wind-energy-fine/

[19] Trey Cox, quoted in a good article in the American Bar Association journal, early 2010: http://www.abajournal.com/magazine/article/the_war_of_winds/

[20] Mike Logsdon of Invenergy, quoted in http://www.oregonlive.com/news/index.ssf/2009/03/oregon_wind_farms_whip_up_nois.html

[21] Such limits, when not concretely tied to measurements of ambient noise in the area, are generally chosen under the assumption that ambient noise is around 40-45dB (a reasonable *average*, but misleading for night limits), or that night ambient sound levels are 30-40dB. It should be noted that while it's common for industry and local regulators to suggest that turbine noise of up to 10dB higher should be no problem, acousticians generally point to a 5dB increase as clearly audible, and 10dB as the level that will begin to trigger significant annoyance; also, the pulsing and other aspects of turbine noise considered elsewhere in this report tends to make the sounds more easily audible, and more annoying, than many other intrusive sounds.

[22] Such investigations have taken place near the Willow Creek Wind Farm in Oregon (see http://www.windaction.org/news/25280) and in Vinalhaven, Maine (see http://aeinews.org/archives/592)

[23] Oregon's night noise limit is 36dB; see http://aeinews.org/archives/663

[24] See Oerlemans and Schepers, from Wind Turbine Noise 2009; details in the Recent Research section of this report.

[25] Justin Lindholm, of Linden VT, in a letter to the editor: http://caledonianrecord.com/main.asp?SectionID=3&SubSectionID=19&ArticleID=48177&TM=49190.16

[26] Note that some other acousticians aren't so quick to completely write off low frequency noise as a concern; a Google search or visit to one of the anti-wind websites will turn up one of several critiques that were published in the wake of the release of this report.

[27] This seemed to be the case in the AWEA/CanWEA report on noise and health issues, which may also have extracted Pederson's data for "very annoyed," separating it from her combined data for "very" and "somewhat" annoyed. In any case, the industry report succeeded in reporting that annoyance is always under 10%, which appeared to be the goal.

[28] Quoted in the NY Times: http://greeninc.blogs.nytimes.com/2009/12/04/study-no-impact-on-property-values-from-wind-turbines/

[29] An interview with this farmer ran as an ad in the Chilton, WI, Times-Journal in 2007. For the full text, see http://www.windtaskforce.org/profiles/blogs/wisconsin-farmer-has-regrets

[30] Curt Kindschuh, a former leader of a wind farm noise group in Wisconsin, said lingering disagreement has created lasting ill will among friends and neighbors. Kindschuh said he no longer is on speaking terms with a cousin who joined other landowners in welcoming Invenergy into the community. Even at a family funeral long after the wind farm was approved, Kindschuh said, he did not share a word with his cousin. "That's the sad part," he said. "There's so many people out here with so many hard feelings." See http://www.greenbaypressgazette.com/article/20100124/GPG0101/1240647/1207/GPG01

[31] Dennis Stillings, quoted in the Indianapolis Star: http://www.windaction.org/news/22588

[32] Personal communication, May 2009. These conversations included the claim that at least one farmer who leased land to the wind farm had stopped doing business at a store owned by someone who had spoken up.

[33] Vinalhaven represents one model: a local utility coop moving toward generating power locally rather than buying it from afar. In other communities, wind companies have begun offering locals or towns to become co-owners of wind farms; this is partly designed as a way of generating more positive "buy-in" from the local community; though such approaches can be viewed cynically, it is often part of an authentic attempt by companies to become partners with locals and encourage ongoing open and constructive dialogue, as well as a more just balancing of the costs (noise, visual) and benefits (financial) of the wind farm.

[34] There are about 12 families within a half-mile of the Vinalhaven turbines, with some people further away also affected by noise (including the resident who is most vocal, who says noise at his house on a hill 3300 feet away is "unbearable."). In personal communication with both the wind farm manager and one of the neighbors, both affirmed that some neighbors feel uncomfortable being the focus of controversy, and so frame their comments to others differently depending on who they are talking to (i.e., they will acknowledge

that the noise is bothersome when talking to other neighbors who are affected, but downplay their issues when discussing it with others).

[35] In 2009 alone, we saw the US EPA (Lawrence Berkeley National Lab) report on property values, the AWEA/CanWEA report on health effects (primarily focused on "wind turbine syndrome"), and the Pederson and Waye papers on annoyance, none of which reported any direct correlations. (all are noted with full citations, summaries, and links in the Recent Research section of this report)

[36] Both sides bury the paradox one layer deeper, as well. Industry groups continue to stress (and perhaps be believe) that turbine noise is hardly worth considering, being always at or near ambient and less loud than urban people live with all the time. Meanwhile, many activist groups who *do* oppose wind farms in general (sometimes on landscape aesthetic grounds, but more often based on larger doubts about the overall economic and power-generating efficiency of wind farms as a contributor to the power grid) rely on critiques of noise standards and stress the noise impacts of wind farms, because this is a topic that is concrete enough to use as a foundation to challenge development plans, both in community debate and the legal arena.

[37] DOE property values study: http://aeinews.org/archives/529
Scandinavian surveys: http://aeinews.org/archives/456
And see also this less formal survey of residents near a Wisconsin wind farm:
http://aeinews.org/archives/465

[38] See http://www2.macleans.ca/2009/08/12/ontarios-big-windy-gamble/

[39] Search any of the sites mentioned in Footnote 3 to find one of several detailed critiques of this study that were written after it was released.

[40] http://greeninc.blogs.nytimes.com/2009/12/04/study-no-impact-on-property-values-from-wind-turbines/

[41] Noted in Hanning (see summary in Recent Science section of this report, page 12)

[42] Download MN DOH report: http://energyfacilities.puc.state.mn.us/resource.html?Id=24519
See AEI summary: http://aeinews.org/archives/456

[43] For a quick introduction to some of these correlations, see this paper on the federal National Institute of Health website:
http://www.ncbi.nlm.nih.gov/pmc/articles/PMC2072857/
The quick summary, by M. Nathanial Mead, is entitled Noise Pollution: The Sound Behind Heart Effects. Excepts:
The noise threshold for cardiovascular problems was determined to be a chronic nighttime exposure of at least 50 A-weighted decibels, the noise level of light traffic. Daytime noise exposures also correlated with health problems, but the risk tended to increase during the nighttime hours…Chronic high levels of stress hormones such as cortisol, adrenaline, and noradrenaline can lead to hypertension, stroke, heart failure, and immune problems. According to a review of the research in the January–March 2004 issue of *Noise and Health*, arousal associated with nighttime noise exposure increased blood and saliva concentrations of these hormones even during sleep. "Taken together, recent epidemiologic data show us that noise is a major stressor that can influence health through the endocrine, immune, and cardiovascular systems," says Prasher. Other recent support for an association of cardiovascular mortality with noise comes from a study published in the 1 January 2007 issue of *Science of the Total Environment*. The results showed an 80% increased risk of cardiovascular mortality for women who judged themselves to be sensitive to noise. "Given these findings, noise sensitivity is a serious candidate to be a novel risk factor for cardiovascular mortality in women," says Marja Heinonen-Guzejev, a research scientist at the University of Helsinki and lead author of the paper.

[44] See this year-end feature in Renewable Energy World on offshore wind in Europe and the US:
http://www.renewableenergyworld.com/rea/news/article/2009/12/optimism-in-offshore-wind-a-market-buzzing-with-activity

[45] Pile driving for foundations is a well-known source of dangerous sound levels; nearby fish can be killed, and dolphins avoid these sounds at distances of several, or even tens, of miles. A special concern is that this construction noise, which has so far been fairly rare, may become widespread, especially during the temperate season, so that large regions of the coastline might experience elevated underwater noise levels. Reassuringly, it appears that underwater noise from operating wind farms is minimal. For more on this, see http://aeinews.org/archives/543 , and peruse AEI's lay summaries of field research at http://acousticecology.org/scienceresearch.html and http://acousticecology.org/scienceresearch2008.html

[46] See http://aeinews.org/archives/623

[47] Among the states that have established formal offshore advisory panels, task forces, and initiatives are Georgia, North Carolina, Virginia, Maryland, New Jersey, Rhode Island, and Maine. Maryland, Virginia, and Delaware have signed a Memorandum of Understanding to create a formal partnership to collaborate on transmission, supply-chain facilities, maintenance, and advocating for federal policies to support wind development. A good source for ongoing coverage of offshore (and terrestrial) wind planning is North American Windpower, a trade magazine: http://nawindpower.com/

[48] See this report from the shore of Lake Ontario, where a wind farm on an island is "readily heard" at 2 to 3 miles, and sometimes as far as 7 miles: http://aeinews.org/archives/347

[49] See http://crispgreen.com/2009/09/statoilhydro-launches-first-full-scale-floating-wind-turbine/comment-page-1/

[50] For more on deep offshore wind, see http://aeinews.org/archives/472

[51] See http://aeinews.org/archives/376 and
http://www.nature.org/magazine/autumn2009/features/index.html

[52] See http://www.rspb.org.uk/ourwork/policy/windfarms/map.asp
Scottish Natural Heritage previously released a broader "Strategic Locational Guidance" for wind farms, focused on mapping key natural heritage sites; for more on this, see
http://www.snh.org.uk/strategy/pd02b.asp
And, see this letter from the National Trust, another UK natural heritage group, and the RSPB, advocating nationwide spatial planning, with attention not only to natural heritage, but also to identifying areas with good wind resources:
http://www.nationaltrust.org.uk/main/w-statement-strategy-response.pdf

[53] See http://aeinews.org/archives/504 for a good overview, with links to presentations from a recent Marine Spatial Planning symposium hosted by NOAA's Office of National Marine Sanctuaries.

[54] See http://www.oceancouncil.org/site/

[55] See http://aeinews.org/archives/281 and
http://minnesota.publicradio.org/display/web/2009/08/03/wind-turbine-noise/

[56] See http://aeinews.org/archives/691

[57] See this post for a link to a good article in Macleans: http://aeinews.org/archives/366
And this post for summaries and links to a good three-part feature in a local paper:
http://aeinews.org/archives/513

[58] See http://www.cbc.ca/canada/ottawa/story/2009/10/19/win-turbine-legal-challenge563.html?ref=rss

[59] See http://www.cbc.ca/canada/prince-edward-island/story/2008/12/23/pe-wind-assessment.html

[60] See http://aeinews.org/archives/630

[61] See http://aeinews.org/archives/227 and http://www.theglobeandmail.com/life/health/study-to-determine-health-effects-of-turbines/article1210357/

[62] See http://aeinews.org/archives/513 and http://www.orangeville.com/news/article/240838--moe-pledges-ongoing-research-on-turbines-health

[63] See http://aeinews.org/archives/644 and http://www.asahi.com/english/Herald-asahi/TKY201001180410.html

[64] In both cases, personal communication of preliminary data; more complete analysis and interpretation is yet to come.

[65] See the Wikipedia entry on nocebo at http://en.wikipedia.org/wiki/Nocebo

[66] Personal communication, Andy Moorehouse, University of Salford. Indeed, some low-frequency noise researchers encourage people to NOT focus on such sounds, since they may well be haunted by them once the are noticed.