Low Frequency Noise and Infrasound

(Some possible causes and effects upon land-based animals and freshwater creatures)

A literary comment
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SUMMARY
The adverse effects of low frequency noise (LFN) and infrasound are generally understood although not widely appreciated because by and large, up until recently most creatures do not encounter them for long periods of time or at levels that are perceived to be dangerously low.

Furthermore, general observations of the effects of these types of sound in respect of land-based creatures other than humans are largely conspicuous by their absence. There also appears to be a dearth of information relative to those inhabiting freshwater.

Which might presuppose that LFN including infrasound poses them little or no problem. Such a premise cannot be discounted but until explored seems to leave a knowledge gap that could be significant. This literary report has combined a variety of study findings and concludes there is a case to answer when land based animals and freshwater creatures are exposed to noise at low Hz levels.

Because of the limitations of our hearing it would be easy to suppose that noises beyond our receiving range do not exist and should therefore be of no concern to us. Yet both very high and extremely low inaudible sounds may be harmful to us and other animals with similar but not identical ranges of hearing.

Different people perceive sounds differently and much depends upon the individual levels of tolerance and what to them constitutes disturbance. Other creatures have lower acceptance levels, as their survival is more reliant upon instinct and interpretation of unusual sounds as a source of danger.

Human acceptance of unwanted sound is subject to the test of reasonability where each case of complaint is considered upon its own merit. Measurement criteria help assess levels at which hearing damage may ensue or a nuisance is established.

With other animals the threshold of reasonability can only commence with human standards applied judgementally to each creature and the environment in which it thrives, this in itself may be unreasonable.

To gauge effect of LFN and infrasound upon land based and freshwater creatures then concentration should be focussed upon intensity and frequency as much as upon speed of travel. Sound travels faster in a mass of greater density than air. Therefore a greater pressure level is also delivered suggesting a perturbing situation might exist for both freshwater dwellers and land based creatures diving under freshwater water in close proximity to sound sources emitting high intensity LFN over long periods of time.

Sources of infrasound and LFN are many and varied with constant new additions. Some are controversial for reasons including noise emissions. Wind turbine generators were raised as a noise concern some years ago. Yet only recently have reports been released by the wind industry with results of desktop studies and none seem to have been conducted on wild animals at wind farms.

A UK press release in 2005 suggested blame for the death of baby seals was due to mother seals aborting their pups through disturbance from pile driving for foundations for off shore wind turbines. Elsewhere some studies have shown that sea mammals, fish, birds and animals exposed to excessive LFN and infrasound has caused them harm.

The hearing abilities of creatures other than man are difficult to determine. Even with sea mammals where studies have been concentrated because of fears surrounding noise created by human activities, only relatively little research exists into the range of hearing.

Whales, dolphins and porpoise have all shown signs of distress from exposure to varying levels of noise at low frequencies and from a variety of sources. Research has shown fish ears are damaged by noise from repeated use of under water air guns and behavioural studies determined the fish became disoriented and consequently were vulnerable.

There are a great number of articles that include reference to the effects of infrasound upon humans. The frequency ranges are recorded in many of these and the overall result always appears to depend upon the exposure time when coupled with the dB and Hz levels.

A few seconds is all it takes at very low Hz and high dB levels before severe problems arise. Even at a level of dB normally found comfortable for listening to music for example, if the Hz level is low then a significant adverse reaction has been reported.

There is reason to suppose that similar effects would also occur with wild animals if exposed to the sounds for long enough periods. The presumption must be that as soon as they felt uncomfortable they would move away from the zone of discomfort. A term more properly described as, disturbance and displacement, which in the case of protected species would be contrary to appropriate legislation.

The concerns of the effects of infrasound are clearly real whether they are upon humans, marine life or land based and freshwater creatures and in extreme cases the results of high levels of exposure could be lethal. Even relatively low levels can be debilitating and create disturbance.

Laboratory studies upon animals have been reviewed with quite chilling results, as it clear that deformities, damage and impairment occur to the subjects with regularity. Admittedly the animals were contained and subjected to exposure times of several hours per day at moderate to high intensity levels of LFN and infrasound. Yet fish and aquatic creatures contained in ponds and lakes would certainly be unable to escape whatever the level of sound intensity or duration of exposure.

Other experiments signify that indirect consequences can arise from exposure to LFN due to the masking effect. Sounds from wind turbines are believed to have disguised the danger of rotating blades and caused the death of large numbers of birds. A report concluded that birds probably couldn't hear the noise of the blades as well as humans can and would be unable to see them because of motion smear.

Constant road noise raises the ambient levels and could affect creatures because of the masking effect. Less frequent but regular sounds might create just enough habituation as to be dangerous and occasionally (such as in country lanes) lull creatures from hiding at lethal moments.

Estimates have been made that bird song will attenuate at the rate of 5dB per metre for a bird 10metres above ground level in an open field to 20dB per metre for a bird on the ground in a coniferous forest. Therefore any high volume of noise of a virtually permanent rate, such as continuous nearby traffic flow could mask communication attempts.

Studies have been made of the effects of noise upon some bird species and quite clearly low frequency noise played a significant role in creating bird disturbance/displacement and was sufficient to cause serious reduction in breeding numbers in the study areas.

Vocal communication plays an important part in the social interaction of many creatures and the imposition of noise from man-made sources could potentially disrupt the ability of species to communicate or it might introduce new and possibly disturbing behavioural factors into social groups.

Aircraft noise and sonic booms have been blamed for reduction in egg laying by domestic poultry. The use of military aircraft at supersonic speeds resulted in some successful claims for damages following alleged injury or loss involving livestock.

Goats have been adversely affected by exposure to jet noise resulting in reduced milk yields. Pigs suffered excessive hormonal secretion as well as water and sodium retention after being subjected to continuous noise over several days.

Wild mice captured from a field at the end of an airport runway were compared with mice from a rural field not exposed to high levels of aircraft sounds and noise was concluded to be the dominant stressful factor causing adrenal weight differences.

Mobile telephone masts emit signals of a low frequency nature and operate in pulses. House sparrows have declined in urban areas where technology producing low frequency noise and infrasound has increased in tandem with the decline. Mayhap there is a causal link.

Recorded noise from a miscellany of sources including machinery, military hardware, electrical and diesel engines, roller coasters and many others have been used in experiments upon sheep and lambs and the results have shown increased heart rates, respiratory changes and reduction in feeding.

Anthropological sources of LFN and infrasound are increasing and will continue so to do. There is clearly a cause for concern because of the likely effects upon wildlife and current protective measures seem inadequate.

Thus it is recommended that better environmental assessments be made to accompany all planning applications involving erection or construction of plant, machinery, buildings, infrastructure or other potential sources of low frequency noise and infrasound, irrespective of project size.

The measurement methods should be reviewed to embrace ‘C’ Weighting and ‘G’ Weighting as well as the usual ‘A’ Weighting so that a proper appreciation of the extent of LFN and infrasound is achieved before, during and after the noise source is installed.

Moreover, regarding larger sites continuous wildlife monitoring and reporting should be in place with conditions attached to planning consents that an order for immediate cessation of the noise source can be made without the need for further deliberation if found detrimental to creature well being.

INTRODUCTION

Despite a plethora of articles reporting the apparent results of low frequency and infrasound upon certain forms of marine wildlife, no studies seem currently available in respect of the impact of this type of noise upon wild land based and fresh-water creatures and whether it be might be harmful.

A vast range of tests, reports and speculation spanning the sublime to the ridiculous covers research into low frequency and infrasound plus the possible, probable and actual distress caused to some sea creatures as well as humans.

Yet a wealth of other creatures relies on their sense of hearing and indubitably is exposed to and experience low frequency noises. In the case of those living in the wild, good hearing is quite simply a survival aid.

Even some invertebrates without conventional auditory receptors register vibrations and use them for either communication or as warnings. The acoustical energy that many invertebrates can sense allows them to survive.

Creatures have evolved senses including those of hearing for reasons of assisting in procreation, communication and protection. The latter includes defence from the danger of predation or to enable them to find food.

Apart from some species of marine and land mammals, the need by other creatures to harness and utilise infrasound for their own benefit has not apparently been of importance. Neither has the requirement to identify and avoid infrasound been particularly necessary. This may explain why the ecological process has not generally equipped them with hearing ranges to detect such low levels of noise.

Inhabiting the land, sea and air in tandem with humans may have changed the situation. Shipping emits low frequency sound, as do lorries, aeroplanes and wind turbines. For many species it has become increasingly difficult to survive especially those prone to disturbance or reliant upon prey driven out by human encroachment.

Quite what detrimental effects are caused by sounds below the hearing threshold of creatures that hitherto have had no need to detect them is open to conjecture. After all does it matter for example; that a rabbit cannot hear a sound from something, provided it is not going to be eaten by whatever emits it?

We know from concerns by environmentalists studying marine mammals that the increasing output of very low levels of sound waves from anthropological sources can cause them to suffer. Could similar noise be unwittingly affecting animals, fish and other creatures on land and in fresh-water?

The adverse effects of low frequency and infrasound are generally understood although not widely appreciated because by and large, up until recently most creatures do not encounter them for long periods of time or at levels that are perceived to be dangerously low.

Could the appreciation of danger change as the regularity of exposure increases? We already know that roads, railways, housing, factories, agriculture and airports are just some of the sources of disturbance causing creatures to retreat and die from the development of the human race.

The inventiveness of mankind continually creates new technology often at the expense of other species either directly or indirectly. There are innumerable instances of pollution from human errors many resulting from the introduction of technological products.

Sometimes belated steps are taken to try and rectify or reduce the damage and perhaps eradicate the causes. Lead free petrol and restriction of CFC gases are quite recent examples but it usually takes a long time before the problem is identified, longer for remedial action and longer still for it to be effective.

The topic of so-called global warming is currently occupying a great deal of political, commercial and scientific time. The acceleration of climate change is generally accepted to have been induced by human activities and is seen by some as the largest current threat to all living creatures.

Consequently it seems further technology must be applied to try and combat what is considered one of the main causes of the situation, the emission of noxious substances from the use of fossil fuels. But is a possible calamity being replaced by a probable disaster?

Both land and sea are being littered with wind turbines, some of which are very big pieces of equipment. These machines are being 'sold' to the public as a panacea because they harness a renewable and natural resource (wind) and seemingly allow production of energy without any significant levels of pollution.

Emphasis is placed upon the amount of carbon dioxide and other emissions they prevent from being generated when similar levels of energy are secured from the conventional sources burning fossil fuels.

Promoting the positive aspects of energy generated from wind power is to be expected but there are also negative issues. One of which is seen as the creation of low frequency noise as the turbines labour to produce a satisfactory end product.

Wind turbines make a noise. This is inevitable but it is the type and level of noise that has to be considered. Understandably most concern has been shown over the effects that these large generators have upon humans and to a lesser extent birds and bats.

Initially with the early and smaller type of turbines very little notice was taken of any low frequency sound they might have produced. More concern was shown over higher frequency noise leading to design modification and to a limited extent more care over choice of sites.

Now with the substantial increase in size and number of these machines infrasound has begun to be considered as a possible problem. Reports of people suffering in strange ways from hitherto undiagnosed complaints following the erection of turbines relatively close to their homes meant there was a real cause for concern.

This has lead to the production of a series of reports analysing the probable level of infrasound made by this machinery on land and what effects prolonged exposure would or would not have on humans. This proliferation of research has not specifically mentioned the effects this type of noise could have on other species. Yet other creatures have ears and nervous systems.

In the UK attention has been given to the turbines with foundations on land elsewhere those erected in the sea have also been considered as problematical. Seawater is a better conductor of sound and contains species particularly vulnerable to the projection of low frequency noise.

Land based turbines however, may be placed within the vicinity of fresh-water, which also conducts sound more efficiently than the earth. Seemingly however this has escaped comment in the reports published in response to the concerns over any impact of low frequency sounds.

Furthermore, general observations of the effects of these types of sound in respect of land-based creatures other than humans are largely conspicuous by their absence. There also appears to be a dearth of information relative to those inhabiting fresh-water. This might presuppose infrasound poses them little or no problem.

Such a premise cannot be discounted but until explored seems to leave a knowledge gap that could be significant. A phrase often quoted is that the absence of evidence is not the evidence of absence.

Apparently therefore, a need arises to initially garner information of possible relevancy and attempt to correlate and assimilate facts that could be applied, to amongst other living things, land-based fauna and fresh-water fishes.

Accredited publications, desktop information, established scientific data; practical field studies and in depth analysis of enquiry into the causes and effects upon specific wild land mammals of Great Britain for example, are simply not available to call upon.

Conducting practical tests upon live wild animals in their natural environment is the obvious method of establishing what if any distress would be caused by partial or prolonged exposure to low frequency noises.

This form of experimentation has both ethical and practical drawbacks and should be considered the instance of last resort. Some work however, has been done on domestic cats and dogs without unduly exposing them to dangerous levels of infrasound and the results may be of interest.

Infrasound studies have also been conducted as laboratory experiments upon rats and guinea pigs with some rather disturbing results. Exposure at quite low Hz levels and moderately high intensity caused significant changes to vital organs.

Perhaps measurements and observation at sites containing large wind turbines might allow the opportunity for scientific study. Unfortunately without a full species count before installation of the machines it would be difficult to assess if noise of any type let alone that emergent from low frequency sound or infrasound had been adversely effective.

Discussion with turbine manufacturers might be beneficial for securing particulars of anticipated noise emission levels, as the machinery they produce should have to undergo rigorous safety tests. Existing data on sounds measured at wind farms with onsite emission levels may be available and would be helpful.

Consequently analysis of this knowledge and of acoustic technology generally plus the findings of accomplished persona who have already commented upon low frequency and infrasound in a variety of ways is a logical starting point.

The ostensible lack of data other than that relative to specific effects upon non-marine creatures or humans could at first glance be considered as a hindrance preventing informed comment upon the subject.

Conversely a second look could show a beckoning blank canvas and such a standpoint is an irresistible lure.

In essence the comments made in the following pages are not scientific other than where they are founded upon proven formulae or text book knowledge and may at times be considered subjective.

I believe they are based upon common sense and hopefully may open the lid covering a topic ripe for detailed research. For without it the consequences upon our unsuspecting natural fauna may be intolerable.

I hope the challenge is compelling.

WHAT IS INFRASOUND?

A dictionary definition is, ‘having a frequency below that of sound’.

Consequently in order to define infrasound in an easily perceived manner we must first understand the meaning of sound and that, if you forgive the phrase, is not as simple as it sounds!

One reason for the lack of simplicity is the complexity of what we actually hear and how the listener distinguishes this at the moment it is heard.

Another is the astonishing diversity of sounds or noises that are constantly with us. The background is never really silent as some level of sound is always present. This is called the ambient sound.

Our ears and those of other animals are amazing pieces of technology. The intricacy of components that make up an ear and how it receives and interprets sound have intrigued generations of scientists.

The human ear contains structures essential for both the sense of hearing and sense of balance. The eighth cranial nerve (made up of the auditory and vestibular nerves) carries nerve impulses for hearing and balance to the brain.

As our ears serve a dual-purpose, damage to either hearing or balance can be painful, dangerous, debilitating or downright unpleasant.

Sound waves cause the tympanic membrane (eardrum) to vibrate. The three bones in the ear (malleus, incus and stapes) pass these vibrations on to the cochlea. The cochlea is a snail shaped, fluid filled structure in the inner ear. Inside the cochlea is the organ of Corti.

Hair cells are located on the basilar membrane of the cochlea. The hair (cilia) of the hair cells makes contact with another membrane called the tectorial membrane. When the hair cells are excited by vibration a nerve impulse is generated in the auditory nerve. These impulses are sent to the brain.

New sources of sound are being continually produced and some of the sounds themselves are also perceived as new, although in most cases will simply be a variation of an old theme. Rather like music where a collection of the same notes placed in differing orders produces a range of sounds, some pleasant and others awful.

Which is the best or worst arrangement may well depend upon an individual’s perception of the ‘tune’. Generally the more melodic the more widely spread is the agreement, but what if the sound cannot be heard?

Because of the limitations of our hearing it would be easy to suppose that noises beyond our receiving range do not exist and should therefore be of no concern to us. Yet both very high and extremely low inaudible sounds may be harmful to us and other animals with similar but not identical ranges of hearing.

Some sounds will have occurred previously and gone unreported or unnoticed but the problems of the effects of noise have increased and by far the most problematic are those caused or created by human actions.

In many instances noise has become intolerable and legislation has been necessary to protect human health. No law deals with the specific effects of noise upon other creatures although Acts of Parliament and International Conventions apply in more general ways such as disturbance of habitat.

In 1999 the World Health Organisation (WHO) produced a report admitting noise was problematic, complex in its makeup and difficult to assess in so far as the impact upon people is concerned.

This admission must also apply to all other creatures with hearing capability and it should be the responsibility of mankind to consider these effects with a marked degree of importance.

Frequent noise is potentially more of a nuisance than that emitted infrequently, yet frequency could be a matter of conjecture. Annually could be frequent in some circumstances and sufficient to drive species from their natural surroundings.

Indeed sound issued at irregular intervals might be more of an aggravation than that produced with regularity. Regular occurrence might lead to habituation. Bird Scaring devices for instance have adjustable timers and are allegedly more effective when firing intermittently.

The WHO issued guidelines on community noise but there are so many sources of noise that to list them individually would be difficult in the extreme. Perhaps therefore it is not surprising they did not mention low frequency noise from wind turbines for example. Mayhap because it seems the problem has only relatively recently become a public issue.

Some limited comment was made however regarding low frequency noise and they exemplified ventilation systems disturbing rest and sleep even at low sound levels. They also said ‘it should be noted that a large proportion of low frequency components in a noise may increase considerably the adverse effects on health’ and ‘the evidence on LFN is sufficiently strong to warrant immediate concern’.

Different people perceive sounds differently and much depends upon the individual levels of tolerance and what to them constitutes disturbance. Other creatures have lower acceptance levels, as their survival is more reliant upon instinct and interpretation of unusual sounds as a source of danger.

Human acceptance of sound is subject to the test of reasonability where each case of complaint is considered upon its own merit. Measurement criteria help assess levels at which hearing damage may ensue or a nuisance is established.

With other animals the threshold of reasonability can only commence with human standards applied judgementally to each creature and the environment in which it thrives, this in itself may be unreasonable.

Sound is multifaceted and can amongst other things; echo, resonate, reverberate; be stored for later reproduction and travel huge distance. Other aspects in play are loudness, tone, pitch, timbre, intensity, frequency, continuity, exposure, acceptability and what each of these means at any given moment.

Loudness for example is a listener’s auditory impression of the strength of a sound and tone is sound of a distinctive frequency unlike sound across a range of frequencies, which is known as broadband noise.

Sound of a level, continuous or streaming nature over an unvaried duration of time is known as equivalent continuous sound.

Certain sounds can appear to be transient because they seem to raise, peak and fall if the source moves towards and then away from a fixed point. Examples are a jet flying over or a train passing by and are called sound exposure levels (SEL).

J. C. Doppler, an Austrian physicist first noticed in 1842 how sound appeared to shift in conjunction with the movement of the source. Henceforth it was known as the Doppler shift or Doppler effect.

The speed of sound depends upon the elasticity and density of the medium through which it travels. The measurement based upon the velocity in dry air at standard temperature and pressure (STP) is 331 metres per second or 750 miles per hour and is the generally recognised ‘speed of sound’. Increasing air temperature by 10°C increases the air speed by 6mps thus the sound barrier is variable.

The sound barrier is the point at which something travels faster than the speed of sound. An aircraft is a prime example and as it approaches the speed of sound it experiences a sudden increase in drag and loss of lift. These are caused by the build up of sound waves, which then create shock waves at the front and back of the aircraft.

Ernst Mach another Austrian physicist first identified what would happen long before the barrier was broken by manmade flight. Mach numbers are named after him and are the ratio of the speed of a body or fluid to the local speed of sound, Mach 1 refers to local speed.

When the 'barrier' is broken by a flying object (usually an aircraft) it moves from subsonic to supersonic speed and creates a sonic boom. The shock waves created spread out and sweep across the ground behind the object often causing a double bang.

The speed of sound also increases with the density of the medium through which it travels**.** The medium is the means by which the sound is carried. Those most commonly identified are air or water but all kinds of mass can be conductive including the earth and human or animal tissue.

Examples of the speed of sound through conductive mass are water 1,500mps, iron 5,000mps with granite slightly higher. Sound will not travel through a vacuum because of the lack of mass.

Sound waves are known as compressional waves. Sound is caused by an oscillation in pressure creating stress particle displacement and particle velocity in a medium that results in an auditory sensation made by the particle fluctuation.

The compressed waves carry sound energy and the matter through which they travel vibrates in the same direction as the wave is travelling. The pressure oscillation or movement is stimulated into causing a vibratory effect that produces waves of energy. For purposes of simplicity it is the waves hitting our eardrum that we hear.

The strength of sound interpreted by the listener and called loudness is actually the average deviation above and below the static value. In turn it is dependent on sound energy and frequency, intensity, tone and then judged by the importance gauged by the listener's own attitude.

Loudness due to a sound wave is called sound pressure and is the physical resonance to sound pressure and intensity.

Resonance is the effect best described as being similar to the sound of blowing across the top of an empty bottle. It is caused by the increase in amplitude of vibration of an acoustic system when forced to vibrate by an external source and occurs when the frequency of the applied force is equal to the natural vibration frequency of the system. Large vibrations can be damaging.

Sound level meters measure sounds over a time period and then produce an average. Consequently they may not give an adequate impression of the disturbance of fluctuating sound. A gunshot for instance, would be a single sharp intervention of noise that would simply be included in the average.

The energy expended during sound wave vibration is identified as intensity and is actually the rate of flow of sound energy. This flow rate is measured in intensity units and these are called decibels (dB) a dimensionless unit which denotes the ratio between two quantities that are proportional to power, energy or intensity.

One of these quantities is a designated reference by which all other quantities of identical units are divided. The sound pressure level in decibels (dB) is equal to 10 times the logarithm (to the base 10) of the ratio between the pressure squared divided by the reference pressure squared.

If that were not confusing enough the study of sound is called acoustics where the reference pressure used are called micropascals.

Acoustics is the science of sound, including its production, transmission and effects. The acoustics of a room for example, are those qualities that together determine its character with respect to the perception of sound.

A single micropascal is one millionth of a pascal and a pascal is one newton per square metre. In water the common reference is 1 micropascal and in air 20 micropascals.

The latter is close to the absolute threshold for a normal human listener when emitted at a frequency of 1,000 Hz and is known as the sound-pressure level (SPL).

The micropascal references for air and water are 26 decibels (dB) apart, which whilst appearing small is significant.

The significance arises when comparing sound in air with sound in water because it is just one complication amongst many and considerable care is needed when making such evaluations.

Apart from the difference in reference pressure levels the impedances of air and water are not the same, which affects the power flow creating a different intensity even if the pressure levels are the same.

The need for comparing sound in air and in water arises frequently because of the differing and sometimes radical effects the same source of sound can have when applied to the two mediums simultaneously.

For example placing a swimming pool on a hotel roof. The sound of a diver plunging into the water has limited effect upon poolside sunbathers but to the occupants of a bedroom immediately beneath it is magnified and could be unbearable.

Similarly sound from a land-based source placed beside a pond would extend into the water and gain intensity. Imagine the effects upon the pond life if the sound was continuous. Creatures with legs and wings could escape but fish and other aquatic species do not have that luxury.

Fish can detect an angler's footfall long before his movement is noticed. A stone tossed into one end of a pond can disturb fish at the other. Low frequency sound from a bank-side source would travel in air across the surface slower than beneath the water and the pressure in the latter would be greater. Hence the sound would be 'felt' even if not actually 'heard' and be disturbing.

The area and depth of the pond, clarity of water, weed growth plus the nature of the bottom, composition of banks (earth, concrete, stone etc) and surrounding vegetation would all play a part in varying the effective level of disturbance. Added to these factors would be the Hz and dB levels of the sound as well as all the other features briefly touched upon in earlier paragraphs of these notes.

Mammals frequenting watery habitats such as Water Voles and Otters are prime examples of creatures with sensitive hearing. Yet voles often live alongside roads, bridges and railways intensively used by humans without apparent disturbance and otters are known to close their ears and nostrils when under the water.

Would either creature record hearing underwater noise? Surely they must because they have ears. The otter by closing ears and nose is not just keeping out the water but also attempting to prevent pressure damage to delicate membranes.

Could they 'hear' infrasound? Not if it were below the threshold of their 'normal' hearing but their nervous system would respond in a tactile manner and receive sensation. These are the type of questions that must be answered when embarking upon a study of the effects of low frequency noise upon animals in their landlocked kingdom.

Sound that passes through a medium like air or water produces a wavelike motion of compression and refraction. Wavelength is the distance between two identical positions in the cycle or wave and is similar to ripples or waves produced by dropping a stone in water.

Length of a sound wave varies with frequency. Low frequency equals longer wavelengths. The length is not the distance each wave travels but the measurement of the individual wave.

Sound waves have an enormous range of scale the extent of which is normally known as amplitude and are usually portrayed in frequencies. These are delineated in Hertz (Hz), which is the frequency of sound expressed by cycles per second (CPS). Our ears are sensitive to some of these frequencies.

Our sensitivity or 'hearing' normally registers frequencies between upper and lower levels of 20,000Hz and 20Hz. This is often referred to as the audio frequency range although sound as low or lower than 2Hz is capable of being heard by some humans.

Frequencies above 20,000Hz are named ultrasonic or ultrasound and below 16Hz are called infrasonic or infrasound, although sometimes the 20Hz level is used for convenience.

Infrasound, which is usually considered to be below the range of normal human hearing (20Hz), is nevertheless still heard but is not interpreted as being heard even if the vibrations are felt elsewhere on the body.

Strange as it may seem this has been shown to be true through experimentation at a concert hall in 2003[1]. Live music was played to an unsuspecting audience and afterwards they were asked for their reactions.

165 (22%) out of 750 in attendance confessed to unusual feelings of uneasiness and sorrow and experienced chills down their spines or nervousness including revulsion and fear. Some had increased heart rates or sudden memory of an emotional loss.

This scientific exercise was conducted by producing infrasound with a 7metre length of pipe and added to some of the four pieces of music played.

Neither the audience nor one of the scientists carrying out the experiment was aware which pieces were adulterated with 'silent sound'.

Questionnaires were issued and it was discovered that the odd sensations were only felt or experienced during the pieces accompanied by the infrasound.

The level of infrasound played has not been published but some organ pipes produce frequencies as low as 16.4Hz so the addition of an extra pipe suggests it was intended to produce an even lower Hz level.

Obviously some of the audience may normally have been able to hear sound at that level but the exercise still confirmed that the effect was unpleasant.

Sound heard by humans and considered as unwanted is more commonly called noise. The word noise is readily understood until trying to elaborate upon the meaning. The concert audience in the infrasound experiment did not hear a noise in the conventional sense but some were undoubtedly disturbed.

Infrasound is therefore sound emitted at low and very low levels of frequency and in general, is inaudible to the average human.

Other creatures however have different hearing levels and are able to discern frequency beyond and below the human range. Therefore it seems reasonable that if they heard the same infrasound as the human concert audience some would also have undergone an unpleasant experience.

Unlike the humans however they would probably have left early.

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[1] The Purcell Room, London

MEASUREMENT OF INFRASOUND

In many cases speed of sound through the earth and water is just as relevant to the production of infrasound as the speed of sound in the air.

Earthquakes produce seismic pressure waves that have been recorded as travelling through strong rock at about 6-7km per second (about 4 miles per second). Compared to air speed at 331 metres per second (1,086 feet per second) that is around 20 times as fast.

The speed at which a sound wave travels however is often less important than the frequency a sound is emitted and the intensity at which it is delivered.

For example the speed of sound waves emitted by a ticking watch do not normally matter as the frequency is of more interest for time keeping purposes. The intensity is also important, too great (loud) and it might be invasive. A human heart will try and tune to the regular pulsating of a clock on the bedside table.

Conversely the speed of sound emitted by a jet engine might be problematical because of both the speed of travel and the intensity of the pressure waves striking the ear.

To gauge the effect of infrasound upon land based and fresh-water creatures then concentration should be focused upon intensity and frequency as much as upon speed.

Low frequency sound and infrasound are normally separated for general classification purposes. This would seem to be for no other reason than one of convenience although two bands are often quoted.

Sounds with frequencies between 20Hz and 900Hz or by some definitions 16Hz and 400Hz are considered to be of low frequency. Infrasound is taken to be frequencies below 20Hz or 16Hz.

Loudness is the yardstick understood by most people although as has been seen even that is not simple to define as much depends upon the listeners perception in the first place.

What is loud to one person is acceptable to another. Yet at moderate levels, low frequency sounds are judged to be less loud than high frequency sounds when the sounds are of equal intensity.

Equal loudness contours are used to determine perceived loudness of a single frequency sound. Complex sounds consist of a variety of frequencies and the system developed to identify sound in such a manner is called A-weighting.

A-weighting is a general 'industry' standard and is used to obtain an index measure of community noise and expressed in A-weighted decibels (dBA).

Frequencies are weighted to simulate sounds of equal intensity at low sound levels and pure tones. Different level limits have to be used for different source types.

Problems arise if a single weighting is used for various sound pressure levels, as it cannot reflect the perception or other adverse effects of different noises.

Equal loudness contours based on broadband noise often are not applicable to community noises. This means there are limitations of A-weighted sound pressure level as a measure of loudness.

Another method of weighting has been designed for infrasound. It is called G-weighting and adopts assumed hearing contours with a slope of 12dB per octave from 20hz down to 2Hz. There are no established criteria for assessing low frequency noise levels in Great Britain.

When assessing the dB output of an air sound in water a figure of 26dB must be added. For example a super-tanker radiating noise in air at 164dB has an equivalent noise in water of 190dB. Which incidentally is louder than a jet engine. These are only approximations as amplitude often varies with frequency.

Sound moves about 4.5 times faster in seawater[2] (1,500mps) than in air (331mps) and faster still in warm water (although it will also increase with a rise in air temperature). Wavelength and frequency are related because the lower the frequency the longer the wavelength.

More specifically, the wavelength of a sound equals the speed divided by the frequency of the wave. Therefore a 20Hz sound wave in air is under 17metres long (331mps/20Hz = 16.6metres) whereas in water it is 75 metres in length (1500mps/20Hz = 75metres) and for land 325metres (6,500mps/20hz).

Descending below the surface of the sea slows the sound speed with decreasing temperature but pressure increases with depth and this causes the speed to rise again. In a deepwater channel for example, the sound waves bend or refract towards the area of minimum sound speed. Thus bend up and down repeatedly and can travel thousands of metres without very much loss of power because they are effectively trapped. This is known as a SOFAR (Sound Fixing And Ranging) channel.

Infrasound is not monopolised by manmade objects as it can occur naturally. Examples include the wind and waterfalls. The level, intensity, regularity and location of manmade low frequency noise are what appear to cause concern and of course being emitted where none existed previously.

During 1998 the US Navy commenced tests with equipment they called their Low Frequency Active Sonar (LFAS) system. The intention was to measure the effects of various levels of low frequency sound waves on singing humpback and sperm whales.

The test area off the island of Hawaii was one of the whales main breeding and calving grounds.

Concerned environmental groups indicated the decibel (dB) sound levels to be used in the experiment would exceed the sound of a jet plane engine at take off. No doubt they used this example as the general public could relate to the noise level and felt it unfair to subject the whales to this type of disturbance

The Navy rebutted the environmentalists' claims as inaccurate and on their behalf the National Marine Fisheries issued a statement. This advised the acoustic power of a jet at take off (180dB air) generates about 100 kilowatts. The acoustic power of the LFAS speaker (200dB water) would generate about 1 kilowatt or the equivalent of 1% of the sound level of a jet engine.

Notice the subtle differentiation between the level of decibels (dB) where one measurement relates to air and the other to water and also the reference to acoustic power. It seems the figures were not comparing like with like especially as sound does not react in water the same as in air.

Acoustic power is actually acoustic intensity and is not what is measured. It is acoustic pressure that matters and the change in pressure produced by the sound wave is what should be recorded. Sufficient alteration of acoustic pressure can cause pain in humans.

The law readily appreciates this and noise protectors are required under the auspices of such legislation as the various Health and Safety at Work Acts. Even relatively low levels of change can create confusion. A neighbour playing loud music whilst you are trying to sleep or study is a common example.

Suffice to say it transpired the information issued on behalf of the US Navy by accident or design had confused the issue by mixing their methods of measurement. The result was that it appeared the output from their LFAS system was much less powerful than the public perception of the sound of a jet plane at takeoff.

[2] Sharon Nieukirk, NOAA Ocean Explorer

Perhaps a more accurate illustration would have been to express the pressure levels generated by the sound underwater rather than compare decibels (dB) in totally different conducting mediums.

One person[3] did just this and used the figures supplied on behalf of the Navy and published his findings. Taking the energy output of 100 kilowatts (jet plane) and 1kilowatt (LFAS loudspeaker) he calculated even if the engine did generate 100 times the acoustic power of the loudspeaker the pressure wave from the latter was about 6 times stronger than the former.

He also utilised the decibel measurements quoted in the statement and equated them to air and water respectively. In this case the pressure level would have been something like 33 times greater in water, than in air, which is probably why it was not used on behalf of the Navy in rebutting the example.

The experiment went ahead and all the whales apparently left the area shortly after the tests commenced. This caused the Navy to cease testing prematurely and seems to have proved that whatever level of sound waves generated, the whales disliked them to such an extent that they left the breeding, feeding and calving grounds.

Other reasons may have caused the whales to leave but none that were recorded by the whale watchers. Furthermore it seems the following year there were far fewer whales that returned to the test area yet plenty elsewhere in the region.

Without knowing the Hz level at which the LFAS system was tested it cannot be categorically stated at what level the US Navy discovered (if indeed they did) that it caused disturbance to the whales.

It seems self evident however, that if a loud speaker releases acoustic intensity of around 200dB at source into a medium that has the capability of increasing pressure many times over then a serious amount of discomfort would be felt by the recipients.

After all the pain threshold generally quoted for humans is around 120dB -140dB in air. This means the normal bearable levels with some discomfort to prolonged exposure. Once these levels are exceeded they start to cause pain that gradually increases with the rise in decibels (dB) until it is unbearable and damaging.

On the other hand unless the pain threshold for a whale is known the effects of the broadcast cannot really be understood or appreciated. The difference between the ear of a whale and a man is considerable and the hearing range is not compatible either.

Land animals will desert habitats violated by noise and birds will often fail to return to a nest that has been disturbed even when eggs or young are present. Why should whales be any different? Yet they frequently return to areas where small boats and human ‘watchers’ appear and apparently without distress.

On the balance of probability alone it seems that at one end of the spectrum the whales simply did not like being disturbed and at the other might have experienced physical pain or even hearing damage. Either way it was caused by the deliberate attempt to expose them to the effects of infrasound.

Many other factors relating to the Naval experiment are also unexplained. For instance how far away was the equipment from the nearest whale? Did they follow the creatures or purely operate from a static location? These are simple but important questions because of the manner in which sound travels and loses pressure over distance.

The reference points for measurement in both air and water are based upon a distance of one metre from the source of the sound. (The Navy generated sound of 200dB was a powerful blast at this distance). Without hindrance the sound would radiate symmetrically. This is called spherical spreading and the acoustic

[3] Lee Tepley Ph.D. Physics

intensity decreases inversely with the distance squared and the pressure decreases inversely with the distance.

In other words without interference the sound wave dissipates regularly over distance and time until it probably disappears entirely. Hence the reason why a 'normal' sound a long way away from the source does not seem as loud as when up close. Yet as always with matters of sound there seem to be exceptions.

The whispering gallery in St. Paul's Cathedral springs to mind. The listener upon pressing an ear to the inner wall of the dome can hear an otherwise inaudible whisper from the opposite side of the chamber. In such a case the enclosed dome magnifies the sound. Could water act similarly?

Sea water in its natural environment is in a constant state of flux due to tides, wind, rain, large mobile objects like boats and because it is a fluid 'bounces' off rocks and shores etc. It also has a greater density than fresh water so any resistance to sound waves will differ to the water found in lakes, ponds, rivers and the like.

The movement and temperature of the sea will affect the manner in which it conducts sound waves. Cold water is more dense than warm. Moreover the depth will be a factor as well as the type of seabed because of the properties of resonance, reflection and absorption. Even the surface of the sea where it meets the air will distort the spherical spread.

In shallow water it seems the pressure waves are affected considerably and decrease approximately inversely to the square root of the distance from the source. This is called cylindrical spreading and would be extremely difficult to calculate accurately if the seabed was not of uniform flatness or consist of homogeneous material.

We know that water and air convey sound waves differently even before other complications are introduced. A simple published comparison[4] where all aspects of interference are disregarded confirms that a spherical sound source radiating a given pressure in ordinary freshwater when compared with the same source in air generates an intensity ratio about 5,000 times greater.

This is a very considerable pressure increase indeed and begins to explain why so many studies have been conducted into the effects of infrasound on marine creatures. Allowing for the greater density (about 1.5 times) of seawater it confirms why environmentalists are concerned.

Remember sound also travels faster in a mass of greater density than in air. Therefore the much greater pressure level is also delivered quicker making it more difficult to escape repetitive sounds

Furthermore it suggests a perturbing situation might exist for both freshwater dwellers and land-based creatures diving under freshwater in close proximity to sound sources emitting high intensity low frequency noise over long periods of time.

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[4] The National Academy Press

INFRASOUND CONCERNS

The use of sonar has not been the only cause for apprehension involving low frequency sound. Offshore drilling platforms used by the gas and oil industry and more recently the erection and prospective placement of wind turbines has featured strongly as worrying features in so far as the effects upon marine creatures are concerned.

Wind turbines seem to be causing more trepidation than drilling platforms and perhaps rightly so because of the sheer number already in place and the prospective proliferation as a reaction to the disquiet of climate change predictions.

Another reason for the focus upon turbines is by reason of where they have been placed and are likely to be erected in the future. The shallower regions of coastal waters, estuaries and perhaps the larger inland areas of water such as Lake Erie, USA are all considered ideal because they embrace some of the windier regions of the planet.

A recent press article[5] confirmed a tower rising 165ft above the surface of Lake Erie and three miles offshore has been installed to accommodate a weather station. The purpose being to gather data over a two year period as a pre-curser to installing wind turbines on the ecologically sensitive western end of the lake.

Unlike turbines off the seacoasts they would be in freshwater that freezes. A wildlife biologist has expressed concern because of the effects of noises and vibrations on creatures as small as mayflies that at one stage in their lives burrow beneath the lake sediment.

Oil drilling platforms have also posed problems in the sea. They cause low frequency noise that continues all the time they are in operation. Air drills are used that emit high intensity levels of infrasound and the pumps run around the clock. Wind turbines also emit more or less continuous output (when the wind blows).

Wind turbines are also situated on land where the effects upon the flora and fauna are easier to monitor but are nonetheless disturbing. Many instances of bird and bat deaths have been recorded. The wind industry has belatedly shown a degree of concern and there are recorded instances where chosen sites have been abandoned in deference to the potential impact upon wild life.

Accordingly it might be supposed, that if wind turbines were shown to have a substantial deleterious effect upon large sections of marine or land-based fauna, proposed sites where the exposure and danger to those creatures was most likely, would not be developed.

Unfortunately this is not always the case and besides, such a policy does nothing to reduce the risk where lesser immediate creature damage is concerned. Furthermore only limited steps have been taken to try and avoid mistakes from the past placement of turbines.

The wind industry has hitherto been slowly reactive rather than speedily proactive to the plight of birds and bats in relation to the problems caused by their turbines. The attitude always appeared to be one of first instance denial and it was not until overwhelming evidence was produced showing the mortality rates, that attempts were made to ameliorate the situation.

Some similarities appear to be developing with regard to low frequency noise emitted by wind turbines. Although it must be accepted that no known creature deaths have yet been recorded as the result of exposure to such noise the industry reaction seems to have been one of denial before investigation.

Infrasound effects upon humans from wind turbine generators were raised as a concern some years ago. Yet only recently have reports been released by the wind industry with results of desktop studies and none seem to have been conducted on wild animals at wind farms.

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[5] The Toledo Blade, Ohio – An article by Tom Henry, September 4th 2005

Neither do they appear to involve people monitoring. Whereas a medical practitioner[6] has studied the effects upon a group of her patients, all of whom live close to a wind farm and the initial results appear to endorse the concern that exposure to low frequency noise emitted by the turbines does have a detrimental affect upon health.

The lack of accumulated research on humans does nothing to dispel fears and leaves the wind industry open to accusations of concealment. Nor do they appear to have taken the next logical step to discover what the effects might be upon mammals other than humans.

Outside of the wind industry there is some evidence of research and an independent report[7] sponsored by a number of interested parties including the Society for Conservation of Marine Mammals was produced in 2003. It concluded that both harbour porpoises and harbour seals reacted to the water bourn simulated sound of a 2 MW wind turbine.

Operational underwater noise emitted at 8 metres a second by a 550 KW wind turbine was recorded from the sea in Fortune Channel, Vancouver Island, Canada and modified to simulate a 2 MW turbine. The replayed sound emitted maximum sound energy between 30Hz and 800Hz with peak source levels of 128dB at 80Hz and 160Hz.

Calm days were used and 375 porpoise groups and 157 seals were tracked. Porpoise echolocation clicks increased by a factor of two when the sound source was active. Seals surfaced at larger distances from the sound source. Both species therefore can detect low frequency sound generated by off shore turbines.

The report highlights the German Exclusive Economic Zone (beyond 12 miles off shore) of the Baltic and North Seas where power companies have applied for permits to build 30 large wind farms with a possible capacity of generating over 60GW of energy.

If all these wind farms were realised this would comprise 12,000 wind turbines, each of 5MW capacity (of which only a prototype exists) or 30,000 of the 2MW class. The area needed for such development would cover some 13,000km^2 and some sections are densely populated by harbour seals and harbour porpoises.

Other aspects of the report refer to the known problems relating to the release of high-intensity low frequency sounds in the sea. They propagate over long ranges and can mask echolocation sounds or calls from marine animals including predators or prey, disturb natural behaviour, cause hearing damage and physiological distress.

The report also states that during construction and operation of wind turbines, low frequency noise is emitted into the water. Referring to recent studies they indicate seals and harbour porpoises can hear sound in the frequency range typical for these operations.

In addition comment is made upon other experiments showing free ranging harbour porpoises leave an area when pingers have been operated to produce artificial sound. The inference being that any unusual sound causes the creatures to abandon an area.

Elsewhere it seems seals may also experience other more severe problems from wind turbines. A press report in 2005[8] said a wind farm at Scroby Sands off Great Yarmouth, Norfolk was blamed for the deaths of baby seals. It appears some of the pregnant seals were so disturbed by pile driving for foundations of wind turbines they aborted their pups. (Pile drivers emit infrasound as high as 230dB).

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[6] Dr Amanda Harry

[7] Behavioural reactions of free-ranging porpoises and seals to the noise of a simulated 2MW windpower generator - 2003

[8] The Mirror Newspaper – Reported 6th June 2005

Conversely a report prepared for the New Zealand Energy and Efficiency Authority[9] asserts that in so far as humans are concerned there is no reliable evidence that would indicate any effects when infrasound is present at a level below the human hearing threshold.

Whilst it is accepted this particular comment was made in the context of trying to identify any problems that infrasound from wind turbines may cause to humans, no reference was made to other animals and it is open to challenge, as there are references elsewhere to an opposing point of view.

Indeed there is a disease called Vibroacoustic Disease (VAD) resulting from exposure to high intensity, low frequency sound and infrasound. The condition is described as a chronic, progressive, cumulative systemic disease.

Admittedly the studies of the disease appear to suggest that it is environments with high intensity sounds over 110dB coupled with low frequency sounds below 100Hz that place people at most risk yet clearly do not preclude symptoms at dB levels below ordinary human hearing.

Neither do the studies exclude the effects upon animals with a similar hearing range to humans nor those that encompass ranges with lower cut off points.

The hearing abilities of creatures other than man are difficult to determine. Even with sea mammals where studies have been concentrated because of the fears surrounding the noise created by human activities, only relatively little research exists into the range of hearing.

There have been investigations involving harbour porpoises where it seemed wind turbine noise at source might be above their hearing range. But, the porpoises' hearing range depends on sound radiation and cylindrical spreading of low frequency sounds appears to change the picture.

The behavioural report following study of noise from a simulated 2MW turbine in respect of porpoises and seals previously mentioned does comment on this aspect. After making mathematical corrections to determine where and when the spherical sound wave from the turbine source became a cylindrical wave it discovered harbour porpoises could possibly hear the noise from a wind turbine.

Although not fully proven it opens the debate and would explain the creatures agitation when faced with the low frequency sounds that were hitherto believed to be inaudible to it.

Because of the lack of study in respect of land-based animals and infrasound it is necessary to look at the frequency hearing ranges of some of our more familiar creatures and domestic dogs are a good example.

Some animal species can be trained to respond to sound stimulus and can learn to make selections using rewards. Canines are particularly good subjects. Pavlov's dogs and the animal fired into space in a Sputnik confirm it works.

Setting up two dispensers containing food and drink and training animals to select one or the other by using pure tone sounds at varied frequencies (Hz) and different loudness intensities (dB) should enable mapping of the creatures hearing range.

Experiments of this nature have been done[10] and the results published. In general it was found that dogs had slightly greater sound sensitivity (detected lower intensity sounds) than humans whereas cats had greater sensitivity than dogs.

The greatest sensitivity in dogs i.e. the frequencies that can be detected at the lowest intensities was in the frequency range of 4Hz to 10Hz. One dog (a poodle) heard a tone at the low frequency of 40Hz but an

[9] Bel Acoustic Consulting – Low Frequency Noise and Infrasound from Wind Turbine Generators: A Literature Review
[10] Lipman & Grassi, 1942. Heffner, 1983

intensity of 59dB was required for it to be detected. Most of the other dogs didn't respond until the stimulus frequency reached 62.5Hz.

On the other hand the poodle also heard a 4Hz tone when it was at an intensity of –4dB, which is a very soft tone. (The logarithm of a number smaller than one is a negative number, which explains why a negative tone was expressed). The same dog also heard an 8Hz tone when it was played at 3.5dB intensity.

There was no systemic relation seen among the dogs between high frequency hearing sensitivity and head size, body weight or tympanic membrane area. Presumably lower frequencies could have been established as 'heard' if louder stimulus was used and likewise for high frequencies.

Utilising information provided by the experiments and a variety of other sources a chart comparing the hearing ranges of a number of species is shown below: -

Species	Lower Range (Hz)	Upper range (Hz)
Dog	67	45,000
Cat	45	64,000
Cow	23	35,000
Horse	55	33,500
Sheep	100	30,000
Rabbit	360	42,000
Rat	200	76,000
Mouse	1,000	91,000
Hedgehog	250	45,000
Ferret	16	44,000
Bat	2,000	110,000
Beluga Whale	1,000	123,000
Elephant	16	12,000
Porpoise	75	150,000
Goldfish	20	3,000
Bullfrog	100	3,000
Canary	250	8,000
Owl	200	12,000
Chicken	125	2,000

The owl species is not known and all the figures are subject to variation from subject to subject but give a reasonable guide to the probable average levels concerned. Note that most of the dogs in the hearing experiment responded to sounds (62.5Hz), which are below their normal average hearing level (67Hz).

Apart from the ferret, elephant and goldfish it does seem none of the species can actually 'hear' the normally classified levels of infrasound frequency (20Hz and 16Hz), which places them broadly in the same situation as man.

The ranges do however pose certain questions. We have already established elsewhere that man is normally capable of detecting 20Hz and sometimes lower, which suggests the cow for example (lower range 23Hz) might respond in a similar manner to some of the humans attending the concert mentioned elsewhere in this text.

Indeed it is known that milk yields are affected by sound and instances of dairy farmers playing 'soothing' music to their herds are often reported in the press. Logically if bovines can appreciate the classics they would abhor the unpleasant effects of a concert laced with infrasound.

On the other hand the hedgehog with a suggested hearing range commencing at a level of 250Hz would seem to be oblivious to designated infrasound (14Hz or 20Hz). Yet anyone who has approached a hedgehog (they do not have particularly good eyesight) will have seen them 'freeze' at the tread of a footfall.

Their sense of smell might play a part but even once they have detected the onlooker and remain aware of their presence they still react to footsteps. Therefore it seems hedgehogs pick up on the vibrations of quite soft footsteps. The reason is probably due to the tactile reception of the lower frequency sounds.

Another chart[11]displays broadly similar ranges for the animals selected. The only real disparity being in respect of a rat where the lower level is shown as higher at 650Hz as opposed to 200Hz and the upper level is lower at 60,000Hz instead of 76,000Hz.

Differences are to be expected within the same species. Human hearing deteriorates with age as we all too soon discover. Animals suffer similarly as anyone who has 'owned' an elderly dog will testify. Hearing range is also affected by concentration. The child with its head in a good book is an example.

We know that humans 'heard' infrasound at a concert and experienced unpleasant effects. Harbour porpoises and harbour seals detected low frequency wind turbine noise and recent research confirms that elephants communicate by using rumbles at infrasound levels and 'feel' them through their feet as well as when placing their trunks on the ground.

Fish are easily disturbed by footsteps on the waterside bank and the lower reception level for goldfish (20Hz) shown in the chart appears to bear this out. With regard to the ferret perhaps the reason for such a low level (16Hz) is because it naturally hunts under ground where low frequency sounds are emitted by its prey scrabbling in burrows.

The fact that a Goldfish has a lower range identical to that of a human (20Hz) is an interesting aspect. Fish as we know spend their lives under water. When we operate in this environment without earplugs many sounds heard seem muffled and indistinct.

Divers upon hearing the steady beat of the water screw from an engine driven boat have difficulty in pinpointing the craft until it is nearly overhead. It is heard long before it is within vision but appears to be coming from different directions at the same time.

Likewise an observer on land may have problems locating the direction of approach of a Helicopter obscured by low hills or trees until it is nearby. Hence one reason why the military practise tree-hopping attack exercises.

In both cases the low frequency rhythmic sound is spread out by the effect of the surroundings that act as a conductive medium. The source of the diffused sound becomes difficult to identify. This should be neatly shown by the manner in which a shoal of fish reacts when disturbed by low frequency noise.

They should scatter at first because the cause of 'danger' is real but not immediately visible and each fish should act according to its own interpretation of the safest haven. They could then regroup away from the noise source.

We know they can actually be herded by release of regular bursts of sound. Dolphins practise a similar routine when hunting and 'round up' shoals. Why then does a low frequency noise such as dropping a stone into the pond not produce the scattering effect within the shoal?

Any angler will tell you they do not disperse but move rapidly away in unison. This should not happen. Especially if the sound source and cause of fright cannot be instantly located.

The answer is that fish have a lateral line system. This provides information about water flow to each fish. As one fish moves in a certain direction, it creates a flow of water that triggers the fish next to it to follow

[11] H.R Schiffman – Sensation and Perception. An Integrated Approach. 2001

suit. A chain reaction develops resulting in the entire school of fish moving as one large mass in the same direction.

The nervous system of a fish however should be singularly less complex than for a human. They are cold blooded and do not, as far as is known, experience pain in a similar manner to warm blooded creatures. Nevertheless they display elements of fear and are easily disturbed into flight.

Surprisingly fish have two sensory systems that enable them to be aware of their surroundings by sensing vibrational information, both make up what is called the acoustico-lateralis system. These two systems detect sound and vibration respectively and are called the inner ear and the lateral line.

Fish use the lateral line system to detect acoustic signals over a distance of one or two body lengths and at low frequencies (lower than 160Hz to 200Hz). Organs called neuromasts detect the relative motion between the animal and the particles in the surrounding water. These have hair cells that can move, sending nervous signals to the brain.

Fish bodies are closer in density to water than air. Sound waves cause the entire fish to move with the water and sound passes right through their bodies. Bones in their inner ear called otoliths are made of calcium carbonate. These chalk like bones are much denser than water and the rest of the fish, so they move slower than the main body of the creature.

The difference between motion of the fish and the otoliths stimulate cilia on the sensory hair cells. This movement is interpreted as sound. The range of frequencies detected by fish (20Hz – 200Hz in Goldfish) is within the low frequency levels.

Although sensitivity to sound differs among fish species the thing that affects this is the proximity of the inner ear to the swim bladder. This bladder is gas filled and therefore has a much different density to either the rest of the fish or the water in which it lives.

Consequently the swim bladder can be easily compressed by sound pressure waves. The bladder pulsates in reaction to sound waves causing the tissues of the fish associated with it to move. Some species such as carp and catfish have the swim bladder connected to the inner ear via a bony system, which increases their hearing sensitivity.

On balance it seems reasonable to accept a fish would detect infrasound at Hz levels below its normal hearing range, but what degree of distress would be derived can as yet only be surmised. Fish deaths have been recorded from the use of underwater explosive due to pressure waves rather than the direct impact of the explosion.

Only minimal damage need be caused to the lateral line, the swim bladder or inner ear for death to result. The magnitude of Hz levels would seem to be the overriding factor when trying to establish what harm would occur from positioning an infrasound source near to fish habitats.

If infrasound instead of low frequency sound were emitted i.e. at levels below 20Hz then by virtue of the hearing limitations of fish it would be felt and not heard.

Consequently as water is a much better conductive medium than air it would take very little pressure from emitted infrasound to be registered by the fish. The unseen pressure waves would spread just the same as low frequency noise and travel long distances.

It has already been mentioned that sound in water operates at increased pressure over sound in air and we know infrasound in air at a concert caused human suffering. Therefore it is reasonable to suppose a greater degree of distress would be caused in water.

In fact following what is believed to be the first study of its kind and reported in 2003[12] Prof. Arthur N Popper and his colleagues found that loud man-made noise significantly damaged fish in the wild. Their study found the injury to fish ears, and thus hearing, was significantly greater than they had anticipated.

The research took place in Jervoise Bay, Western Australia on pink snapper fish. The noise-maker was a seismic air-gun, a tool routinely used to search for underwater oil deposits. The air-gun sound is sent repeatedly through the water, travels to sub-sea rock strata and back up again.

Fish were placed in a cage at varying distances from the air-gun and exposed to differing levels and repetitions of sound from the gun. When examined, holes were found in the hearing part of the fish ears, in the region where it was expected to find sensory hair cells. The hair cells had either been ripped away or there was evidence that the cells were dying.

The study indicated that unlike humans the hair cells of fish are normally able to regenerate but found this had not occurred after nearly a month. With ears similar to other vertebrates, including mammals, most fish use sounds to detect predators, find prey and communicate to find mates. Loss of hearing can therefore leave fish very vulnerable.

Although fish swimming freely are able to swim away from the sound, the report advised that behavioural studies had shown some fish exposed to air-gun signals did display disoriented swimming behaviour. Prof. Popper said the results of the study suggest caution in using devices that make intense sounds in environments inhabited by fish and mammals.

Another study, this time under laboratory conditions was published online in December 2003[13] and relates specifically to goldfish. The findings following exposure of the fish to high levels of white noise (above infrasound frequency) confirmed they sustained initial physiological stress responses as well as short and long-term hearing loss.

Some interesting comments were also made by the study confirming that a 100Hz tone may be detected by the lateral line as well as by ear hence researchers have not generally performed auditory brainstem response tests below 200Hz, probably to avoid stimulating the lateral line response.

Furthermore due to the 40dB loss of sound energy at the air-water interface determined by Parvulescu in 1964, very little sound was heard outside the noise tanks used to conduct the underwater noise experiments. Consequently no noise from a tank containing a loudspeaker and sound source escaped to the control tank where fish not subject to sound exposure were housed. The maximum dB level used was 170dB underwater.

The experiment also stated that sound is an important means of communication in aquatic environments because it can be propagated rapidly (five times faster than in air) over great distances and it is not attenuated as quickly as other signals such as light or chemicals. Which they conclude is a reason why fishes and marine mammals make considerable use of sound for communication etc.

Whales issue sonar type noises as apparent methods of communication. These sounds fall within the ultrasonic classification (the opposite end of the range to infrasonic) but they also receive infrasound as demonstrated by the disturbance when bombarded with the US Navy signals. Whales are said to avoid areas commencing at 120dB.

Humpback whales and Bottle Nose dolphins are quite vocal and the sounds recorded from their emissions have ranged between 10Hz and 200,000Hz so it is reasonable to assume they hear across a similar range. The intensity of the sounds made are variable and not easy to measure, mainly because with the larger species it is very difficult to get close enough to record the sound without causing disturbance.

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[12] Journal of the Acoustical Society of America – January 2003 issue
[13] Noise-induced stress response and hearing loss in goldfish – The Journal of Experimental Biology

There is a reported instance of a vet being pushed back several feet into the water by distress calls made by a beached whale. This seems to demonstrate they do emit high intensity low frequency sound, either in pain or under some other form of duress. It also shows the force generated by infrasound in water.

An article about sea life and infrasound[14] indicates it is known that certain whales are able to stun their prey with powerful blasts of inaudible sounds. They apparently focus these 'gunshots' on large squid and other fish to paralyse and catch them. In some instances they are reported to have burst their prey by tonal projection alone.

Unfortunately if correct this then begs the question, 'why do they not also damage themselves?' Perhaps because they have the capability of forcing the infrasound waves along a directional course that when emitted at high intensity become virtually unstoppable until striking their target.

This is not as fanciful as it seems because it is well documented that military experiments have been carried out to try and harness infrasonic sound as a weapon. Bullets of acoustic power may seem fanciful but in 1972 an infrasound generator was in operation in France that when activated made people within range sick for hours.[15]

A Russian device that can propel a 10Hz sonic bullet the size of a baseball hundreds of yards is thought to exist. Blunt object trauma is caused to a target when a bolt of high power, very low frequency sound waves are emitted from one or two metre sized antenna dishes.

The US Navy experiment mentioned previously using LFAS upon whales was a military device for anti-submarine warfare. It emits up to 240dB and the US Navy sets 140dB as the maximum level of safe exposure to humans.

In the Second World War, German engineers constructed a prototype sonic 'cannon', which fired a shock (sound) wave strong enough to bring down an aeroplane.[16] Infrasound was used by the Nazis to stir up anger amongst crowds assembled to listen to Hitler.

Hitler also ordered experiments to be conducted on prisoners who were tortured with high intensity low frequency sound emitted by a weapon powered by compressed air.

According to an item of reported BBC news some US interrogators used amplified music including low frequency sound in 2003 to try and 'break' the will of Iraqi prisoners. This incurred the wrath of Amnesty International.

Previously psycho-acoustic tactics were used successfully by US troops in 'Operation Just Cause' in 1989 to remove Manuel Noriega from behind his barricade in Panama and the FBI are alleged to have played all manner of sounds at the Waco siege in Texas to try and disorient their opponents.

Prior to this, in 1973 the British Army tested an 'Acoustic Squawk Box' in Northern Ireland. Two ultrasonic frequencies (the opposite end of the spectrum to infrasound) were emitted and when mixed in the human ear caused giddiness, nausea and fainting. A small beam could be directed at individuals and used as a riot control device.

Earlier (pre-1973) a crowd control device, the Acoustic & Optical, Photic Driver was developed, again using ultrasound, which when combined with flashing infrared lights to penetrate the human eyelid was believed to have been used by the South African Police as an interrogation device.

Although these two examples relate to very high frequency sound it seems the results are similarly harmful where low or high frequency emissions are used with intensity.

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[14] Infrasound by John Cody
[15] Glossary of Non-lethal Weapons Terms, edited by Robert Bunker
[16] Feel the Noise by Jack Boulware

Another illustration was reported in The Toronto Star, Canada on 6th June 2005 when witnesses described a minute-long blast of sound emanating from a white Israeli military vehicle. Within seconds, protesters began falling to their knees, unable to maintain their balance. An Israeli military source, said “the intention is to disperse crowds with sound pulses that create nausea and dizziness.”

Professor Hillel Pratt, a neurobiologist specialising in human auditory response at Israel’s ‘Technion Institute’, says “It doesn’t necessarily have to be a loud sound. The combination of low frequencies at high intensities, for example, can create discrepancies in the input to the brain.”

Later he explained, “that by stimulating the inner ear, which houses the auditory and vestibular (equilibrium) sensory organs with high intensity acoustic signals that are below the audible frequencies (<20Hz), the vestibular organ can be stimulated and create a discrepancy between inputs from the visual system and somatosensory system (that report stability of the body relative to the surroundings) and the vestibular organ that will erroneously report acceleration (because of the low-frequency inaudible sound). This will create a sensation similar to sea or motion sickness. Such cases have been reported and a famous example is workers in a basement with a new air-conditioning system that all got sick because of low frequency noise from the new system.”

There are a great number of articles that include reference to the effects of infrasound upon humans. The frequency ranges are recorded in many of these and the overall result always appears to depend upon the exposure time when coupled with the dB and Hz levels.

A few seconds is all it takes at very low Hz and high dB levels before severe problems arise. Even at a level of dB normally found comfortable for listening to music for example, if the Hz level is low then significant adverse reaction has been reported.

Very low frequency sound can travel long distances, penetrate buildings and vehicles and does not significantly diminish its properties when it changes mediums such as from air to tissue. This is because unlike ultrasound it travels ‘in band’ more effectively due to the propensity of low frequency sound waves to travel in a straight line.

Intermittent bursts of infrasound would presumably not be as damaging as continuous exposure and if the levels of both cycles per second (Hz) and strength (dB) were not high then it is possible that little or no adverse effect would be delivered. Regular or irregular pulsating strong infrasound would however, at least be debilitating.

It is the level of tolerance that must be anticipated if any meaningful comment can be made upon the likely detrimental result of infrasound exposure upon wildlife whether inhabiting urban, suburban or countryside areas.

A research paper, ‘Human Body Vibration exposure and its Measurement’ by G Rasmussen looked at body vibration exposure at frequencies of 1Hz –20Hz. Part of a table shows:

Symptoms	**Frequency**
General feeling of discomfort	4Hz – 9Hz
Head symptoms	13Hz – 20Hz
Influence on speech	13Hz – 20Hz
Lump in throat	12Hz – 16Hz
Chest pains	5Hz – 7Hz
Abdominal pains	4 Hz – 10Hz
Urge to urinate	10Hz – 18Hz
Influence on breathing movements	4hz – 8Hz

A graphical illustration of a 'mechanical man' in the paper indicates the head will vibrate at about 25Hz and the chest wall at 60Hz. The paper then refers:

"Also, in the region 60Hz to 90Hz disturbances are felt which suggest eyeball resonances and a resonance effect in the lower jaw-skull system has been found between 100Hz and 200Hz."

There is reason to suppose that similar effects would also occur with wild animals if exposed to the sounds for long enough periods. The presumption must be that as soon as they felt uncomfortable they would move away from the zone of discomfort. A term more properly described, as disturbance and displacement, which in the case of 'protected' species would be contrary to appropriate legislation.[17]

As already mentioned test results upon humans have been released and the following examples are just some more extracts from differing sources that seem relevant.

According to one publication[18] when discussing the effects of infrasound at the rate of 1 – 10 Cycles per second (Hz) - "lethal infrasonic pitch lies in the 7Hz range. Small amplitude increases impact upon human behaviour in this cycle range. Intellectual activity is first inhibited, blocked and then destroyed. As the amplitude increases some disconcerting responses have been noted and begin a complete neurological interference. The action of the medulla is physiologically blocked and its automatic functions cease."

In another[19] also commenting upon the 7Hz level – "the most profound effects at this infrasonic level occur here. Seven Hz corresponds with the alpha-rhythm frequencies of the brain. It is commonly alleged that this is the resonant frequency of the body's organs and hence organ rupture and death can occur at high intensity exposures."

Scientific Applications and Research Associates (SARA) in America, alleged infrasound at 110-130dB would cause intestinal pain and severe nausea. Extreme levels of annoyance or distraction would result from minutes of exposure to levels 90 – 120dB at low frequencies (5 – 200Hz), strong physical trauma and damage to tissues at 140dB – 150dB and instantaneous blast wave type trauma at above 170dB.

Infrasound Toxicological Summary (USA), November 2001 stated – "When male volunteers were exposed to simulated industrial infrasound of 5Hz and 10Hz and levels of 100 and 135dB for 15 minutes, feelings of fatigue, apathy and depression, pressure in the ears, loss of concentration, drowsiness and vibration of internal organs were reported. In addition effects were found in the central nervous system, the cardiovascular system and the respiratory system."

This summary also confirmed amongst other things that respiration rate was significantly reduced after the first minute of exposure. The heart rate increased during the initial minutes and heart muscle contraction reduced. All of which must have been most unpleasant.

A Polish study, Medycyna Pracy Vol. 55 (1) 2004, p.63 –74 comments as follows:

"There is a growing body of data showing that low frequency noise (LFN) defined as broadband noise with dominant content for low frequencies (10Hz – 250Hz) differs in its nature from other noises at comparable levels. The aim of this study was to assess the influence of LFN on human mental performance. Subjects were 193 male paid volunteers…….LFN at 50dB(A) could be perceived as annoying and adversely affecting mental performance." (i.e. concentration and visual perception).

Some years ago Walt Disney and his artists apparently felt the effects of infrasound released accidentally at 12Hz on one occasion. A cartoon sound effect was slowed from 60Hz via a tape-editing machine and amplified through the theatre sound system. The resulting tone, though brief in duration, made the entire crowd nauseas and the effects lasted several days.

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[17] The Habitats Directive (Bern Convention), The Wildlife and Countryside Act 1981
[18] The Sonic Weapon of Vladimir Gavreau by Gerry Vassilatos
[19] Acoustic Trauma: Bioeffects of Sound by Alex Davies

Moviemakers use infrasound to produce unease and disorientation in the audience. A French film called Irrevérsible used this to considerable effect to highlight the disturbing visual content and increase the tension.

In order to bring the levels of infrasound into perspective it should be remembered that the human brain functions as a transmitter and receiver. In his paper, 'EEG Measurement', G Blundell states:

"The brain operates;	Normal activity	13Hz – 30Hz
	Relaxed	8Hz – 13Hz
	Drowsiness	4Hz – 7Hz
	Deep Sleep	0.5Hz – 4Hz

Interrupting, conflicting or overriding signals of unwanted sound (perceived as noise) at any frequency will have an effect on the brain and associated senses but predominantly auditory functions and those directly connected via the ear. The lower frequency sounds (<20Hz) stand a greater chance of interference with operation of the brain.

The evidence appears to show that harm created by LFN to humans, ranges from simple sleep disturbance (aggravating in small doses, dangerous through fatigue if prolonged) through temporary disablement (sometimes deliberately imposed) to the extreme cases of permanent injury and possible death.

In the circumstances the medical implications are worrisome. A number of studies have been conducted into the health risks caused by body vibration from infrasound, increased cortisol from infrasound, endocrine effects and cardiovascular risks arising from noise exposure. (See Appendix A).

The problem with infrasound is that a doubling of loudness occurs when the level of the sound is increased in air by 5dB and at the same time it becomes about three times as intense. Therefore only a small increase in source sound can be significant.

Erection of barriers can reduce some types of noise and are most effective when close to the source, but are not very effective in tackling low frequency sound and infrasound. These sounds are very hard to muffle as they spread easily in all directions and may be heard for miles and are mostly perceived not as sound but as pressure.

Sounds at low frequencies are not well attenuated by atmospheric absorption[20] and precipitation can affect ground attenuation. Snow can have a muffling effect on the ground but the associated low air temperature can create a noise increase and spread the sound over longer distance.

Reflection of sound by substances of differing acoustical hardness will have an effect. Concrete or water will reflect more than grass, trees or other vegetation. Yet when prominent low frequency components are present the annoyance factor generally increases due to either vibration, greater pressure intensity or a combination of both.

The concerns of the effects of infrasound are clearly real whether they are upon humans, marine life and freshwater creatures or land based animals and in extreme cases the results of high levels of exposure could be lethal. Even relatively low levels can be debilitating and create disturbance.

On the other hand are the known emission sources on land capable of producing damaging levels of sustained sound in habitats frequented by land-based and freshwater creatures or do they just create a nuisance that might cause temporary fright?

Dr P L Pelmar contributed a section to a report commissioned by DEFRA in May 2003 (A review of Published Research on Low Frequency Noise and its Effects by Dr Geoff Leventhall and others) where he reviewed the effects of LFN on health. Within this review he stated, "The results of some animal studies

[20] Source: Bruer & Kiaer (Denmark), Environmental Noise Booklet

reporting adverse effects from infrasound exposure may be relevant for indicating possible human health effects."

The following is a summary of the studies:

a) Vascular – Myocardium

Alekseev (Alekseev et al.,1985) exposed rats and guinea pigs to infrasound (4Hz – 16Hz) at 90dB to 145dB for 3 h/day for 45 days and a single exposure (4Hz – 10Hz) at 120dB to 125dB. The latter led to short-term arterial constriction and capillary dilation in the myocardium. Prolonged exposure led to nuclear deformation, mitochondrial damage and other pathologies. Effects were most marked after 10Hz to 15Hz exposures at 135dB to 145dB. Regenerative changes were observed within 40 days after exposure.

Gordeladze (Gordeladze et al., 1986) exposed rats and guinea pigs to 8Hz at 120dB for 3h/day for between 1 and 40 days. Pathalogical changes in myocardial cells, disturbances of microcirculation and mitochondrial destruction in endothelial cells of the capillaries increased in severity with increasing length of exposure. However, changes were reversible after exposure ceased.

Rats and guinea pigs exposed to infrasound (8hz or 16Hz) at 120dB for 3 h/day for 1 to 40 days showed morphological and physiological changes in the myocardium. (Nekhoroshev and Glinchikov, 1991).

b) Conjuntiva

Male rats exposed to infrasound (8Hz) at 100dB and 140dB for 3 h/day ranging from 3 to 25 days showed constriction of all parts of the conjunctival vasculartture within 5 days (Svidovyi and Kuklina, 1985). Swelling of the cytoplasm and the nuclei of the endotheliocytes accompanied the decrease in the lumen of the capillaries. The capillaries, pre-capillaries and arterioles became crimped. Morphological changes were reported in the vessels after exposure for 10, 15 and 25 days. After 25 days increased permeability of the blood vessels led to swelling of tissues and surrounding capillaries and to peri-vascular leukocyte infiltration. Significant aggregates of formed elements of the blood were observed in the large vessels.

c) Liver

Infrasound exposure damaged the nuclei apparatus, intracellular membrane and mitochondria of rat hepatocytes in vivo (Alekseev et al., 1987). Infrasound (2,4,8 or 16Hz) at 90dB to 140dB for 3 h/day for 40 days induced histopathological and morphological changes in hepatocytes from rats on days 5 – 40. Infrasound (8Hz) at 120dB to 140dB induced pathological changes to hepatocytes from the glandular parenchyma and sinusoids.

Morphological and histochemical changes were studied in the hepatocytes of rats and guinea pigs exposed to infrasound (2,4,8 or 16Hz) at 90, 100, 110, 120, 130 or 140dB for 3 h/day for 5 to 40 days (Nekhoroshev and Glinnchikov, 1992a). Hepatocytes showed increased functional activity but exposures for 25 and 40 days induced irreversible changes. Changes were more pronounced at 8 and 16Hz than at 2 and 4Hz. Exposures impaired cell organoids and nuclear chromatin. Single exposures did not induce any changes in the hepatocytes and small blood vessels.

d) Metabolism

(Shvaiko et al., 1984) found rats exposed to 8Hz at 90, 115 or 135dB exhibited statistically significant changes in copper, molybdenum, iron and/or manganese concentrations in liver, spleen, brain, skeletal muscle and/or femur compared to concentrations in the tissues of controls. Practically all tissues showed significant changes in all the elements for exposures at 135dB. Changes included elevations and depressions in concentrations. The trends were consistent with increasing sound pressure except for some copper values.

e) Auditory

(Nekhoroshev, 1985) exposed rats to noise of frequencies 4, 31.5 or 53Hz at 110dB for 0.5h, 3h or 3h/day for 40 days. Infrasound exposure caused graver changes than exposure to sound at 31.5 or

53Hz. Changes observed after exposure to this acoustic factor included reduced activity of alkaline phosphotase in the stria vascularis vessels and their impaired permeability. Impaired labyrinthine hemodynamics led to neurosensory hearing impairment.

(Bohne and Harding, 2000) sought to determine if noise damage in the organ of Corti was different in the low-and-high frequency regions of the cochlea. Chinchillas were exposed for 2 to 432 days to a 0.5Hz (low frequency) or 4kHz (high frequency) octave band noise at 47dB to 95dB sound pressure level. Auditory thresholds were determined before during and after noise exposure.

The cochlea were examined microscopically, missing cells were counted and the sequence of degeneration was determined as a function of recovery time (0 – 30 days). With high frequency noise, primary damage began as small focal losses of outer hair cells in the 4 – 8kHz region. With continued exposure damage progressed to involve loss of an entire segment of the organ of Corti along with adjacent myelinated nerve fibres.

With low frequency noise, primary damage appeared as outer high cell loss scattered over a broad area in the apex. With continued exposure, additional apical hair cells degenerated, while supporting cells, inner hair cells and nerve fibres remained intact. Continued exposure to low frequency noise also resulted in focal lesions in the basal cochlea that were indistinguishable from those resulting in high frequency noise.

In guinea pigs low frequency pressure changes have been shown to cause head and eye movements (nystagmus) of the animals for square wave pulses with pressure above 150dB (Parker et al., 1968).

f) Brain
(Nishimura et al., 1987) suggested from experiments on animals that infrasound influences in rat's pituitary adreno-cortical system as a stressor and that the effects begin at sound pressure levels between 100 and 120dB at 16Hz. The concentration of hormones shows a slight increase with exposure to infrasound. In the task performance a reduction was seen in the rate of working. It seems probable that concentration was impaired by infrasound exposure.

(Nekhoroshev and Glinchikov, 1992b) exposed rats and guinea pigs to 8Hz at 120 and 140Db for 3 hours for 3h/day for 5, 10,15, 25 or 40 days and they showed changes in heart, neurons and the auditory cortex increasing in severity with increasing length of exposure. The presence of hemorrhagic changes are attributed mostly to the mechanical action rather than to the acoustic action of infrasound. They suggested that changes in the brain may be more important than the ears.

g) Lung
Histopathological and histomorphological changes were determined in the lungs of male albino mice exposed to infrasound (2, 4,8 or 16Hz) at 90 to 120dB for 3h/day for up to 40 days (Svidovyi and Glichikov, 1987). After prolonged exposure to 8Hz at 120Db sectional lungs revealed filling of acini with erythocytes and thickening of inter-alveolar septa; after prolonged exposure to 8 and 16Hz at 140dB sectioned lungs revealed ruptured blood vessel walls, partially destroyed acini and induced hypertrophu of type-ll cells.

These results are quite chilling, as it is clear that deformities, damage and impairment occur with regularity. Admittedly the animals were contained and subjected to exposure times of several hours per day at moderate to high intensity, low frequency and infrasound levels. It would be most unusual for any comparative wild creature (say brown rats, field mice, bank voles or squirrels) to undergo similar exposure times or levels, but fish and aquatic creatures contained in ponds and lakes would certainly be unable to escape whatever the level of sound intensity.

On the other hand the experiments (with the exception of the Chinchillas) ceased after only around 40 days. Noise from factories, roads and other anthropological sources such as wind farms would be virtually continuous for year upon year, although not necessarily at such intensity.

This leads to a question. What would be the result of exposure to low Hz levels at less intensity for 25 years (the projected useful life of a land based wind turbine for example)? Bearing in mind the lowest sound pressure level used in the tests was 47dB (upon Chinchillas) and it seems to have contributed towards ear hair cell degeneration it appears likely there would still be adverse effects. Some species of fish, such as carp live in excess of 20 years.

Would animals become accustomed to the problem if the disturbance was only of a relatively minor level or could even small amounts of disruption lead to abandonment of habitation?

How would fish and invertebrates fair being unable to escape from enclosed pond environments? What degree of creature disturbance or destruction is acceptable or what is unacceptable?

The following two paragraphs are contained within a study published in 1988[21] and whilst the research was predominantly concerned with aircraft noise, particularly sonic booms it called upon a number of previous experiments and findings to illustrate the broad problem of noise upon animal welfare.

Popper and Clarke (1976) studied the hearing of salmon (Salmo salar) in the sea and in the laboratory. The fish responded only to low-frequency tones (below 380 Hz); particle motion, rather than sound pressure, proved to be the relevant stimulus. The sensitivity of the fish to sound was not affected by the level of sea noise under natural conditions, but hearing is likely to be masked by ambient noise in a turbulent river. Sound measurements made in the River Dee, near Aberdeen, Scotland, led to the conclusion that salmon are unlikely to detect sounds originating in the air unless the source is nearly directly overhead, but they are sensitive to substrate-borne sounds. Compared with carp and cod, the hearing of the salmon is poor and more like that of the European perch (Perca fluviatilis) and the plaice (Pleuronectes platessa).

To clarify the effects of construction sounds on fish populations, the change in acoustic environment of Lake Biwa (Japan) caused by dredging was observed (Konagaya 1980b). The response of fish to dredging sounds and the swimming direction of fish near the worksite were studied using acoustic biotelemetry. The spectrum level of the background noise of Lake Biwa was within the limits of prevailing noise of the sea. The sound pressure level of the underwater sound of a dredging boat at a distance of 150metres was about 38 dB, and that of a submerged pipe at a distance of 2metres was 75 dB. The fish showed negative responses and avoided the acoustic field of the worksite**.**

Both examples clearly show that noise and the related water disturbance do have an affect upon fish. Logic suggests this would be the case but what would prolonged exposure do? Perhaps a pointer is another study also reported in the above 1988 paper produced by Karen M Manci and her associates in respect of investigation into the effects of low frequency sound upon Brown Shrimp.

Growth and reproduction of brown shrimp (Crangon crangon) reared in a soundproof box that reproduced acoustical conditions similar to those prevailing in the shrimps' natural environment were compared to those of shrimp from the same source but reared in acoustical conditions prevailing in a thermo-regulated aquarium where noise levels reached 30 dB in the 25 to 400 Hz range (Lagardere 1982). This permanently high sound level resulted in a significant reduction in growth and reproductive rates. To a lesser degree, noise also appeared to increase aggression (cannibalism) and mortality, and to decrease food uptake. Symptoms were extremely similar to those induced by adaptation to stress.

Freshwater shrimp are a food source to many species of pond and lake dwellers. Reduction in numbers could impact severely upon creatures placed further up the dependency chain from fish to reptiles, birds and mammals. Interference at low levels of mortality may not be particularly significant over a wide area

[21] Effects of Aircraft Noise and Sonic Booms on Domestic Animals and Wildlife: Karen M Manci et al.

of population, but the concentrated destruction of small invertebrates over a broad ranging spectrum of habitats could lead to an ecological break down of the food chain with far reaching consequences.

Amphibians such as frogs and toads also rely heavily upon sound for communication and this plays a substantial role in their reproductive behaviour. Most amphibians have complex ears that are dependent upon sound frequency and directionality.

Whilst to the casual listener the croak of one frog may seem very like that of another studies have shown that closely related species, or even local populations of those with disjunctive distribution are known to differ. The vocal harmonics, frequencies and intensities are quite marked. Call duration, repetition and trill or pulsation rates differ widely.

Griffin and Hopkins (1974) measured sound levels of bullfrog (rana catesbieana) choruses at about 20dB SPL in the 1.5 to 2.5kHz frequency band up to 965metres above small ponds. Uninterrupted sound travels upward much farther and more predictably than along a surface so it seems the sound serving as a stimulus to the frogs probably occurs within relatively narrow variation limits.

Acoustic avoidance behaviour was demonstrated in a natural population of the neotropical treefrog (Eleutherodactylus coqui) by a study (Zelick and Narins 1980). The threshold for evasive action at different frequencies varied from 230Hz to 3,420Hz at between 60 – 70dB SPL.

Single tone stimuli (1-2 second duration), spaced at the frogs spontaneous call interval (2 –3 seconds), were presented to the frogs. The creatures redistributed their calls in time such that the calls fell almost exclusively within the brief time window between tone bursts, thereby avoiding an overlap with the tone.

The average background noise level at the frog's calling site was 30dB SPL at 500Hz, 59dB SPL at 1,000Hz and 66dB SPL at 2,000Hz. Thus avoidance behaviour was observed at stimulus levels barely exceeding the noise floor of the frog's environment. Disturbance or confusion by introduction of lower frequency noise could also have an adverse affect upon receptive sensitivity.

What would happen if obfuscation occurred due to the introduction of continuous or virtually continuous infrasound or low frequency noise during the brief breeding cycle of the UK population of frogs and toads? These amphibians are already diminishing rapidly in number and a further possible threat to their survival by a proliferation of noise disturbance could lead to their virtual extinction.

Thunderstorms emit low frequency noise and some species of amphibians are believed to react to the sound perceiving it as a harbinger to forthcoming wet and damp conditions and venture forth to breed. This has been particularly noticeable amongst the spadefoot toad (Scaphiopus couchi), which is not native to the UK but inhabits arid regions of the South-western United States.

Experiments have shown that by revving a motorcycle at around 95dBA these toads leave their burrows and make an assumption that it is time to mate. Should this occur when no damp or wet conditions exist the effect upon their population would be deleterious.

British species of amphibians all tend towards winter hibernation or dormancy and have been recorded emerging to breed earlier than ever before, with a reduction in success rate. This change in habit is believed to be due to the milder, wetter winters of recent years as opposed to the previously colder, dryer conditions. If the 'wake-up' call was also partially dependent upon thunderous conditions then could year round emission of low frequency noise from anthropological sources also be playing a confusing part?

Reptiles such as snakes and lizards appear to rely more heavily upon chemoreception ('smell' via 'taste' through air sampling) rather than sound coupled with vision for survival purposes. Nevertheless it seems they are sensitive to low frequency noise and infrasound. Both Grass Snakes and Adders react to vibration and the former inhabit damp places often entering still water and small streams or rivers in search of prey.

Studies of the Mohave fringe-toed sand lizard (Uma scoparia) in California show it has ability to hear low-intensity, low frequency sounds (Brattstrom and Bondello 1983). Laboratory tests using dune buggy engine recordings at 95dB representative of such a vehicle at 5metres distance from the lizards showed all the creatures exposed to the noise for 510 seconds suffered actual hearing loss.

Shallow burial in the sand was not considered an adequate escape from the sounds and it was felt that exposure to noise of this intensity during the breeding season would have adverse biological effects. A recommendation by Bondello et al. was all unnecessary disturbance from mining, repeated low level jet over-flights and gunnery should be restricted from the immediate area of the dune systems inhabited by the lizards.

The British sand lizard is restricted in habitat and as such is an endangered species appearing mainly in areas of fairly highly classified nature conservation. This does not mean they are completely protected from such eventualities as road building or wind farm erection and could easily fall foul of noise disturbance from such projects. Without proper studies into the effects of low frequency noise and infrasound upon both the habitats and their vulnerable inhabitants what damage might ensue?

Moles live almost exclusively underground. A study in 1978 (Konstantinov) showed that these small mammals (from a group of 30 species of insectivores) had hearing of the lowest frequency and relatively high thresholds. Tests denoted that sound levels of 90dB and above caused mammals to retreat from the sound source, freeze and display a strong startle response, but not necessarily in that order. Sound levels below about 90dB usually caused much less adverse behaviour.

Unfortunately the Hz level of the test noises is not known, but the behaviour pattern is indicative of what might be expected if a wild creature is suddenly faced with the uncertainty of danger from the source of an unexpected noise.

Vocalizations of prey species are sometimes pure-toned calls, which are more difficult to locate than multi-frequency calls. Vertebrates do not locate all pure-toned sounds with the same accuracy. In a controlled test, Isley and Gysel (1975) determined how well nine red foxes (Vulpes vulpes) located 13 different frequencies of pure sound, varying from 300Hz to 34kHz.

Using food as a reward, the foxes were trained to choose the correct location of a 74dB sound signal emitted from one of two possible loudspeaker positions. The foxes located the sound source best from 0.9 to 14 kHz (<90% accuracy) with a slight decrease in accuracy at 8.5kHz (84% accuracy).

They had the most difficulty locating the source at 0.3, 0.6, 18, and 34 kHz (<78% accuracy). Foxes appear to readily locate a wide range of sound frequencies and may have maximized their chances for locating certain calls, which are presumably difficult to locate.

Precise results at the lowest frequency sound (300Hz) utilised are not known, but as included in the least successful bracket for location accuracy lead to the probable conclusion, as might be expected, that use of low frequency or infrasound plays little or no part in hunting/feeding activities. Thus it might be surmised very low frequency sound could be disturbing as the animals would be unable to identify it.

In another experiment audiograms were obtained for two least weasels (Mustela nivalis), using behavioral methods. The hearing range of the least weasel for intensities of 60dB SPL extends from 51Hz to 60.5kHz, with a region of best hearing extending from 1kHz to 16 kHz (Heffner and Heffner 1985). Hearing in the least weasel appears to be similar to other members of the order Carnivora for which data are available.

The high-frequency hearing ability of the least weasel lends additional support to the relationship between functional inter-aural distance and high-frequency hearing, whereas its sensitivity to low frequencies in the absence of obvious morphological specialization of the middle ear makes the least weasel unusual among the small mammals (although not unique as shown with the ferret in the chart on page 21).

Infrasound and LFN effects upon invertebrates do not seem to have been extensively studied, but some mixed findings are interesting. Frings and Frings (1959) reported that flies of the order Diptera showed a startle response at 80-800 Hz (at 80 dB) and at 120-250 Hz (from 3-18 dB above ambient levels). However, the long-term responses to these sounds are not given.

Earthworms have been shown to move toward the surface near roadways at low frequencies (5 Hz) exposing them as a food source for birds. Worm charming competitions have indicated that repeated beating of an earth patch will bring the creatures to the top. This might pose a problem for birds if worms are raised by LFN from sources such as wind turbines by attracting them into areas swept by revolving rotor blades.

Some studies have been undertaken with regard to the use of noise as a deterrent to insects. These have not been particularly successful as sound exposure to even large numbers of insects has been difficult to interpret. Interestingly however Honey bees (Apis mellifera) ceased moving for up to 20 minutes in response to frequencies between 200 and 2,000Hz with intensities varying from 107dB to 119dB (Frings and Little 1957; Little 1959) and did not appear to habituate to the sound.

Conversely midges (Chironomidae) exposed to 125Hz at 13 dB – 18dB above ambient noise caused increased movement to the extent of acting as a possible attractor (Frings and Frings 1959). This may go some way towards explaining why insects seemed to have been attracted to wind turbine blades to such an extent as to reduce power generation[22].

By now it will be apparent that emission of noise clearly poses problems but also many unanswered and possibly unanswerable questions in relation to the affects upon wildlife. In order to go some way towards seeking at least a partial solution to some of the queries raised we must establish the known output of infrasound and low frequency noise from a variety of sources that are likely to be encountered by land-based and freshwater creatures.

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[22] Nature Magazine Vol.412 5th July 2001

SOURCES AND EXAMPLES OF LOW FREQUENCY AND INFRASOUND DISTURBANCE

We know that Elephants and Whales make use of infrasound for communication, as do Rhinoceros, Hippopotamus, Giraffes and Okapi. Alligators take advantage of the conductivity of water to send low frequency sounds to attract a mate and migrating birds use turbulent airflow from mountain ranges as navigational aids.

Land-based mammals in the UK are not believed to use low frequency sound or infrasound for hunting, communication or attracting mates. Where sound is of importance it is usually at the other end of the range, such as with the use of ultrasound by Bats. Yet they are still susceptible as recipients of the lower sound ranges being able to detect them through hearing and nervous systems.

British freshwater fish however, are similar to many of their counterparts in the sea and some fish adapt to both environments, albeit in a limited capacity (estuarine inhabitants and eels for example). Consequently infrasound plays a part in finding food, avoiding predators and choosing mates.

Comment has already been passed on the effects of sonar-generated sounds on marine life including fishes. Other studies have been made in relation to low frequency sound and fish. The following are extracts from some of the published reports of the general effects of underwater noise on fish:

- When marine fish were exposed to sound pressure levels 40-50dB above that in their normal environment (at 40Hz – 1000Hz) severe problems occurred; the viability of fish eggs was reduced and growth rates for fry were significantly reduced. (Banner and Hyatt, 1973)
- A broad band, 140dB sound applied to fish tanks for 20 minutes a day influenced fat stores, growth and reproductive indices. (Meir and Horseman, 1977)
- Studies show harmful effects of even moderate noise on hearing in fish. (Myrberg, 1980)
- As background noise increases, fish hearing decreases. (Myrberg, 1980)
- Intense noise levels (180dB) destroy the hair cells of the auditory maculae resulting in hearing loss. (Enger, 1981)

Mention has also already been made of a report by Lagardere in 1982 that confirmed shrimp reared under sound levels 20dB – 30dB above ambient noise showed significantly reduced growth and reproductive rates, decreased food uptake and increased mortality.

There are freshwater shrimps as well as the marine variety and both serve as an important part of the food chain with many fish preying upon them. In the event that relatively low levels of sound affect their life cycle this could impact seriously upon the predators as well.

Earthquakes, volcanoes, tidal waves and hurricanes are just some of the more extreme sources of natural infrasound. Although the consequential loss from the physical damage can be disastrous the events are not necessarily continuous at any one location and are usually relatively short in duration.

Occasionally a man-induced event will produce brief but tragic results that are recorded by sound monitoring devices. One example was the re-entry of the Space Shuttle Columbia in February 2003 when the sonic booms and subsequent disintegration of the craft were registered.

Prior to satellite monitoring the method of seeking the source of nuclear explosions was by seismic recording of infrasound and of course nuclear blasts are a prime example of infrasound created by human activity.

On the other hand low frequency sound and infrasound created by humans can be transient (shipping, lorries, trains etc.), intermittent (shot blasting, pile driving etc.), as well as virtually permanent and unremitting (wind turbines, oilrigs, pumping stations etc.).

There are many examples of man-made sources of low frequency sound and infrasound and some are included below:

Wind Turbines
Wind turbine manufacturers publish detailed performance reviews of their equipment and normally include noise levels as part of the specification. The sound is measured at source and usually relates to that emitted by the hub at a fixed point above the ground (or sea) and at a selection of wind speeds.

The wind speed is important as the higher the speed the faster the turbine blades are driven and a safety cut off point is inbuilt. Otherwise the turbine on its tower could become unstable.

Wind turbines are designed to operate where it is windy and that includes areas on land and off shore. In both cases the turbine tower has to be secured to a stable base and it is through the base that some sounds are transmitted as well as from the blades and at the height of the nacelle or hub.

Consequently if a turbine is located on land upon a base of concrete inserted below ground level, sound will radiate from the base. This will occur either by transmission from operation of the sails through the fabric of the tower into the footings or as the result of vibration of the construction on its foundations.

Additionally any noise from the bearings in the hub or from revolving blades will also permeate the air.

Should the turbine be placed close to water, such as near to a small pond or reservoir then low frequency sound and infrasound could conceivably travel via the ground into the water. Likewise the sounds conveyed in air would also impact upon the water and as has been commented upon already the effects of differing conductive mediums are considerable.

A lot would depend upon the distance of the turbine from the water and the make up of the surrounding earth plus the presence of any other structures, vegetation or intervening force such as change in wind direction as all could vary the level and direction of sound.

A Danish manufacturer of wind turbines (Bonus Energy) was contacted and they provided the following data in relation to a 1.3MW turbine with different hub heights above ground: -

Hub Height Above Ground	Wind Speed at 10metre Height	Sound Power Level at +/- 2dB(A) uncertainty	Measurement Distance From Turbine
45 Metres	8 Metres Per second	98.9 dB(A)	70 Metres
60 Metres	8 Metres Per second	102 dB(A)	70 Metres

Note the sound power level increases with hub height and no figures were supplied for low frequency or infrasound recorded.

The 60metre tower was described as being of conical, tubular construction enclosed in a steel canopy with 29metre blades producing a diameter of 62metres. The blades revolve at 13 – 19rpm over a swept area of 3000m^2. The tower is hollow with internal platforms spaced to enable ascent without additional safety harness.

The tower, being hollow might produce a Helmholz effect (resonance) thus adding to low frequency sounds instigated by operation of the blades, although this is not mentioned in the literature containing technical data about the turbine mentioned above. Noise would also arise during construction of foundations, erection procedures and servicing.

Underwater turbine noise is not usually included in the manufacturers specification. Obviously if a turbine were located at sea or in a large lake the water bourn sound would differ from its counterpart travelling exclusively in air and be different again from a combination of conductive mediums.

Here are some report findings[23] relating to underwater noise recorded in a study of off-shore turbines:

Turbine Type	Wind Speed (m/s)	Source Level (dB re 1μPa^2/Hz)	Noise Frequency (Hz)
Middlegrunden, Denmark	13	115	125
20 x 2MW 'Bonus' turbines	6	101	125
concrete foundation	6	111	25
Bochstigen-Valar, Sweden	8	108	160
5 x 0.55MW 'windworld turbines	8	108	16
steel monopile			
Vindeby, Denmark	13	113	125
11 x 0.45MW 'Bonus' turbines	13	130	25
concrete foundation			

Notice how the dB levels increase with wind speed and from the larger (MW) turbines, also that the low-level Hz frequencies do not always coincide with higher dB output. In fact the peak noise was 130dB at 25Hz. Only one recording (16Hz) was at infrasound level or below but all others were at low frequencies.

More noise came from turbines on concrete foundations and the result recording a 130dB level was sufficient to reach the pain threshold for humans if emitted in air.

Other noise associated with installation of turbines is pile driving, which can reach source levels of between 150 –230dB and radiate in water up to 20KM (12.5miles). Vessel traffic would also produce additional noise during the construction phase and service or repairs.

The report concluded that physiological and behavioural effects would occur in sea creatures from the effects of underwater noise and vibration caused during installation and operation of wind turbines. In particular displacement both temporary and permanent would occur with habitat fragmentation.

When considering the effects of land-based wind turbines upon freshwater fishes or mammals frequenting a watery and waterside habitat, the level of the sound measurements taken from the generators subjected to the above study are significant.

Clearly quite high dB levels are transmitted and could travel long distances. We know from turbine manufacturers own recommendations as well as other sources that turbines should not be erected close to human dwellings. Why then should they be permitted where other creatures live?

According to the WHO Guidelines for Community Noise 1999, "The annoyance inducing capacity of a noise depends mainly upon its intensity and spectral characteristics, and variations of these with time". The report writers also commented, "It should be noted that a large proportion of low frequency components in the noise may increase annoyance considerably". And goes on to say, "Where prominent low frequency components are present (in noise) they should be assessed".

Presumably annoyance to creatures other than man would also occur if exposed to the same source. The difference being that what transpires to be a nuisance to humans might be a matter of life or death to an animal or fish because of interference with habitat.

Another more recent report was published by DEFRA[24] and concluded, "There is no doubt that some humans exposed to infrasound experience abnormal ear, central nervous system, and resonance induced symptoms that are real and stressful. If this is not recognised by investigators or their treating physicians,

[23] The Humane Society of the US
[24] A Review of Published Research on Low Frequency Noise and its Effects, Dr G Leventhall 2003

and properly addressed with understanding and sympathy, a psychological reaction will follow and the patient's problems will be compounded. Most subjects may be reassured that there will be no serious consequences to their health from infrasound exposure and if further exposure is avoided they may expect to become symptom free".

Three basic points arise here but before raising them it should be understood Dr. Leventhall who led preparation of this report did write separately following the issue of same to emphasise that in his opinion wind turbines did not emit infrasound at sufficient levels to cause any problems at all to humans.

Returning to the points arising. Firstly any 'real and stressful symptoms' suffered by humans would also be incurred by other creatures exposed to the same source(s) of sound(s). Secondly the resulting 'psychological reaction' in humans, if repeated in other creatures would be impossible to treat by reassurance. Thirdly avoidance would be impossible by fishes and other aquatic life trapped in ponds etc.

Regarding the subsequent assurance regarding noise from turbines it does not seem that anywhere in the report were sound measurements secured from underwater or any attention given to the effects upon creatures other than humans. The latter would of course be expected as the report was only concerned with how people might be affected.

According to Bel Acoustic Consulting in their report of June 2004 for the Energy Efficiency and Conservation Authority in New Zealand the sound power level of a typical wind turbine in the 16Hz one-third-octave band is around 105dB at a wind speed of 10mps. The report says, "This means that the sound pressure level at only 100metres distance will be in the approximate range of 50dB to 55dB and this is far lower than the audibility threshold of around 85dB for this low frequency sound".

Unfortunately the wind does not always blow at 10mps and as can be seen from the findings of the Humane Society of the US shown on the previous page both higher and lower wind speeds can produce greater levels of sound. Moreover infrasound as we have seen does not have to be 'heard' to cause unpleasant symptoms in humans and marine mammals and whilst people might not be encouraged to live 100metres from turbines other creatures may not have that luxury.

The Department of Trade and Industry (DTI) have produced public information about renewable energy sources that is freely available from their web site[25] and embraces considerable space explaining the noise produced by wind turbines.

According to the DTI if a turbine produces a sound power level of 104dB(A) then installation of a second turbine with the same power sound level will only cause an increase of 3dB(A). Yet they admit a sound level of 100dB(A) contains twice the energy of a sound level of 97dB(A) and increasing the energy of a sound by 26% raises the noise power level by 1dB(A) or tripling the energy of a sound yields an increase of 5dB(A).

Despite using the above figures as examples it should be noted that elsewhere in the DTI information they indicate modern wind turbines emit sound up to 106dB(A). They also take pains to explain how distance reduces the perceived level of sound and the noise from a wind turbine can reach moderate sound pressure levels (less than 50dB(A)) when the distance from the turbine is between 200 and 300 metres.

According to the DTI most proposals for installation of wind turbines are assessed using the sound limits of 35 – 40dB(A) at the nearest dwellings occupied by those without a vested interest in the project. In other words they should be situated further away than the 100 metres mentioned in the Bel Acoustics report and the 200 -300metre distance shown in the above paragraph.

The lowest levels are stipulated for 'night noise' so as to try and avoid sleep disturbance. Clearly the 'noise' would be unacceptable any closer whether emitted during day or night and must surely also be intolerable to other creatures, especially those unable to escape from the vicinity.

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[25] www.DTI.gov.uk

Another report has been issued by the UK government and published as an accompanying document to Policy and Planning Guide 22 (PPG22) from the Office of the Deputy Prime Minister (ODPM). The accompanying document is over 180 pages long and relates to guidance for various forms of renewable energy projects.

In respect of wind power, paragraphs 45 and 46 in the technical annexe refer to Low Frequency Noise (Infrasound) and insist, "There is no evidence that ground transmitted low frequency noise from wind turbines is at sufficient level to be harmful to human health".

Reference is made to a technical report[26] issued in 1997 on behalf of the DTI which says a comprehensive study of vibration measurements at a modern wind farm was made with measurements being taken on site and up to 1km away in a wide range of wind speeds and direction.

They stipulate the study found that:

- Vibration levels 100metres from the nearest turbine were a factor of 10 less than those recommended for human exposure in critical buildings (i.e. laboratories for precision measurement).
- Tones above 3.0Hz were found to attenuate rapidly with distance – the higher frequencies attenuating at a progressively increasing rate.

The measurements were clearly land-based and seem not to have been taken at the foot of the turbine(s) and then progressively further away but utilise a starting point 100metres distant from the source. More importantly it should be remembered that in 1997 wind turbines were considerably smaller than those currently being erected and therefore required foundations commensurately smaller.

This poses the following questions:

- Why are the DTI relying upon findings from a report almost a decade old?
- Has another report been commissioned on a site with larger and more turbines in situ?
- Surely the measurements should start from as close to the turbine base(s) as possible?

To be reasonably certain that the infrasound from land-based turbines does not affect creatures other than humans the proposed sites should be surveyed in detail for other life forms before construction work commences. Then monitored during erection and operation of the turbines in accordance with international requirements (Berne Convention recommendations[27]).

The French National Academy of Medicine[28] has suggested low frequency noise from wind turbines produces a reality of health risk to humans. They recommend (until alternative proof is found) that installation of wind turbines in excess of 2.5MW capacity should not be closer than 1.5km from occupied houses.

The reasons cited are that considerable information was presented at an international conference on wind turbine noise held in Berlin in October 2005 as well as inter alia, noise evaluation surveys at a French wind plant.

Another recommendation by the academy is to conduct two studies to prove whether noise from wind turbines is harmful. First they suggest turbine noise levels inside houses should be recorded over a time period and secondly health effects properly monitored.

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[26] ETSU W/13/00392/REP

[27] The Bern Convention on the Conservation of European Wildlife and natural Habitats (the Habitats Directive)

[28] Reported in Wind Power Monthly, June 2006

Once again it is understandable why no mention is made of any attempts to measure problems that might be caused to other animals, as the academy is concerned with human medicinal matters. Logically if such noise does impact upon human health it will also affect other creatures, not forgetting if a safety distance of 1.5km applies to people, many other creatures within that band would exist.

The French national Renewable Energy Syndicate (SER) and the French Wind Energy Association (FEE) were not consulted by the academy. They point out their own study has found noise emissions from turbines reach 100dB at rotor height, 55dB at the foot of the tower and 35dB at a distance of 500m. These are generalised findings and are not specific to infrasound levels.

In July 2006 New Scientist magazine issue 2559, carried an article (page 36) that referred to information in another journal[29] by Andrew Gill from the Institute of Water and Environment, Cranfield University. He pointed out a mere 1% of all papers on renewable energy published in the past 15 years considers environmental impacts of wind turbines onshore and none offshore. Highlighting the paucity of ideas of how offshore installations will affect the marine environment and disrupt its wildlife through habitat damage, noise and vibration, electromagnetic fields and collisions with turbines.

Gill points out the marine ecosystem is largely uncharted territory, so wind farm developers often have no way of knowing which sites might be less vulnerable. The same can almost certainly be said of some similar onshore areas, especially those with territories of mixed land and freshwater.

The problem with renewable energy generators particularly wind turbines is where to put them. Mark Avery of the Royal Society for the protection of Birds (RSPB) is in agreement and whilst the organisation welcome technology with the potential to combat climate change they have very real concerns at both the damage they (wind turbines) cause to birds and lack of studies on the subject in countries who embraced wind farms years ago.

Examples of noise from wind farms and the apparent problem caused to animals are sometimes reported and once again New Scientist magazine carried a brief article[30]. Lawrence Rabin of the University of California and his colleagues compared the behaviour of two groups of Californian ground squirrels in similar environments, except that one group lived close to a wind farm.

Recordings of alarm calls were played to each squirrel group. Those living near the turbines were more likely to dash back to their burrows upon hearing the calls and spent more time looking for predators. The study team felt the turbine noise increased the squirrels' alertness, perhaps because of the need to compensate for their reduced ability to communicate through sound.

Enforced behavioural change could have considerable causal chain effects. The squirrels are a food source to predators such as the golden eagle and an acute rise in alertness might reduce the kill rate. This could lower the breeding success of the birds with a resultant reduction in population. The squirrels might also breed less being unable to feed as often leading in turn to fewer being available as prey.

The squirrel burrows are also used as homes by red-legged frog and California tiger salamander. A decreased squirrel population would lead to a shortage of 'dwellings' through habitat loss with in turn, further inevitable changes to the population of those species.

The researchers felt wind turbine noise may affect wildlife communities all over the world. Consequently they consider more care needs to taken over choosing where to site them.

A suggestion that turbine noise disguises danger was the subject of an in depth study in 2002 by R Dooling, Ph.D of the United States National Renewable Energy Laboratory (NREL)[31]. The report focussed upon the hearing capability of birds as a reason for high bird mortality rates following collisions with wind turbines.

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[29] The Journal of Applied Technology – 2005 (Vol 42, page 605)
[30] New Scientist magazine, issue 2549 3 May 2006 (page 21)
[31] NREL/TP-500-30844: Avian Hearing and the Avoidance of Wind Turbines, June 2002

According to the findings birds in general hear best between about 1kHz and 5khz. The report dispelled as myths the suggestion that birds hear better at high frequencies than do humans or other mammals and that birds have exceptionally acute hearing. Stating that ‘ when hearing is defined as the softest sound that can be heard at different frequencies, birds on average hear less well than many mammals, including humans.’

A selection of data on bird hearing was utilised including audiogram plots from 49 species showing the hearing capabilities in the quiet and a selection of those species were plotted showing how they hear in noise. The difference between ‘quiet’ and ‘noise’ being important because of the masking features of the latter and relevant to windy conditions required to drive wind turbine blades.

The conclusion was that birds probably couldn’t hear the noise from turbine blades as well as humans can. In practical terms it is suggested a human with normal hearing can probably hear a wind turbine blade twice as far away as can the average bird.

Wind noise and sounds emitted by wind turbines are mainly low frequency and measurements taken and utilised by the report writer were almost all recorded at a sound pressure level (SPL) of 65dB(A) at frequencies below 1kHz – 2kHz. They discovered that due to some blade defects some turbines whistled and concluded this might help birds avoid turbines.

Adding a whistle emitting an acoustic sound within the hearing range of birds (2kHz – 4kHz) would add almost nothing to overall SPL but might help birds hear the blades. It is believed that as birds approach a wind turbine, especially under high wind conditions, they lose the ability to see the blade (because of motion smear) before they are close enough to hear the blade.

The report hypothesises that louder (to birds) blade noises might result in fewer fatalities. A test by making noise measurements and comparing fatalities at turbines with noticeable whistles with those having no whistles was mentioned but does not appear to have been done.

In compiling the report the various bird species from which avian audibility curves were secured predominantly arose from studies made over the preceding 50 years (39 species) with another 10 that included data from physiological recordings. Birds were typically tested at frequencies between 0.5kHz – 10kHz although not all were tested at exactly the same frequencies.

The birds were subdivided into groups. Passeriformes (songbirds, perching birds), non-Passeriformes (including game birds, falcons, waders, pigeons, emu and parrots) and Strigiformes (nocturnal predators like owls). In general the opinion was there was less variation in hearing sensitivity among birds than among members of other vertebrate groups.

The findings denoted that nocturnal predators detect softer sounds in general than either of the other two groups over their entire hearing range. Indeed the absolute auditory sensitivity of birds, such as the barn owls are unusually low, probably because of their predatory nocturnal lifestyle. (Konishi 1973, Van Dijk 1973, Dyson, Klump and Gauger 1998).

On average, the spectral limit of ‘auditory space’ available to a bird for vocal communication extends over a bandwidth of 0.5kHz – 6kHz. A particular exception being the common pigeon, which is believed to have an unusual auditory sensitivity to very low frequency sounds (Quine 1978; Yodlowski 1980).[32] Some estimates denote they are almost 50dB more sensitive than humans in the frequency region of 1Hz –10Hz (Kreithen and Quine 1979).

According to Dooling, birds are unusual among vertebrates in the remarkable consistency of their auditory structures and in their basic hearing capabilities, such as absolute thresholds and range of hearing. Yet the auditory curves published in the report display differing ranges. These might arise through difference in species size with constraints imposed on low frequency sensitivity in small birds due to body size.

[32] These findings were not included in the chart compiled earlier in this paper (page 18).

Dooling also says that compared to most mammals, including humans, birds do not hear well at either high or low frequencies. Even allowing for the exceptions previously mentioned (pigeons and owls) there are no cases in which birds hear at frequencies higher than about 15kHz. Neither do they generally hear as well as mammals and humans at low frequencies.

Consequently he concludes as most of the energy generated by wind turbines is at lower frequencies (less than 1kHz – 2kHz) this means even in the quiet, a bird would need to be much closer to a turbine in order to hear it, than a human. For example, the human threshold at 1kHz is about 5dB SPL and the average bird threshold at 1kHz is about 20dB SPL.

When the turbine noise is masked and even at night in rural areas there is always some background sound, it needs to be at least 1.5dB above the background noise to be detected by birds. For humans a noise need only be about 0.5dB greater than the background to be 'heard' above the ambient sound.

In order to further research into the masking effects Dooling pursued the effect of noise on signal detection and investigated detection of tones in noise. He found no direct field data available for the former and relied upon laboratory-controlled information to provide estimates. Regarding the latter he obtained critical ratio data behaviourally for 14 species of birds including songbirds, non-songbirds and nocturnal predators.

These species were plotted on a graph. For 11 of the 14 species (which he plotted as an average) he found a signal in the region of 2kHz – 3kHz must be 26dB – 28dB above the spectrum level of the noise to be heard. This average curve follows quite closely the typical pattern of a 2-3 dB/octave increase in signal to noise ratio that is characteristic of these functions in mammals, including humans.

In both mammals and birds, this orderly increase is related to the mechanics of the peripheral auditory system (Behesy 1960; greenwood 1961; Buus, Klump, Gleich and Langemann 1995). Three exceptions however, occurred among the 14 birds, namely the budgerigar, barn owl and great tit.

What the curve described in practical terms is the level in decibels above the spectrum level of the background noise that a pure tone must be in order to be heard. For the average bird it was as described above but not in the case of the three excepted birds mentioned. For the human, the same pure tone need only be about 22dB above the spectrum level of noise to be heard. This represents a difference in masked thresholds of 6dB

In essence because of the inverse square law that applies when measuring sound from a fixed source over a distance, the difference represents approximately a doubling of distance. (Sound decreases as it travels away from the source and a human can still detect a sound in noise at twice the distance a typical bird can).

Noise can of course mask another noise just as it does when masking a tone. Adding noises together (dB plus dB) does not simply increase the sum of the noises, i.e. adding two 60dB SPL noises does not result in a single noise (tone) of 120dB SPL. Neither can adding energy at a single frequency in a broadband of noise simply rack up the total. This is due to energy being summed across the entire noise band being emitted. Thus increasing a single frequency by say, 2kHz only increases the overall noise marginally.

Experiments have been carried out to determine how much a level needs to be increased to be detected by humans. In 1947 Miller discovered it has to increase about 0.5dB – 1dB. Similar data exists for three bird species, the budgerigar, the starling and the barn owl (Dooling, Lohr and Dent, 2000). All three were shown to hear about a 1.5dB change in level of flat, broadband noise. Once again acoustically their discrimination is less than for humans.

Dooling did further research by measuring sound at a wind farm (which is how the whistling effect was discovered) using a reference point 10m (33ft) from the tower. The SPL was recorded including wind noise and turbine blade noise at about 70 dB (A). The ambient noise was constant but as to be expected the turbine noise decreased with distance until at 25m (82ft) from the base of the turbine the blade noise was less than the background noise.

At this point the blade noise would be inaudible to birds, based upon the previous figures. Higher and lower ambient noise levels have a dramatic effect on the hearing distance. If noise increased 10dB to 80dB(A) SPL the blade noise would not be audible to a bird until it was within less than 10m (33ft) of the blade.

The three unrelated species, budgerigar, starling and barn owl all had a value of 1.5dB for detecting noise in noise and it is likely this holds true for all birds. This would represent a clear hazard for all flying birds. Higher ambient noise would arise with higher wind velocity and 80 dB (A) is quite typical so if higher than this the detection distance level of blades by sound would fall further with attendant collision risk. (Note 70dB (A) is considered normal for mild to moderate wind velocities).

Sound and vision normally work in concert. Painting wind turbine blades with different patterns might be thought to aid a bird to see them before hearing the noise and being alerted to the danger. Yet because the two senses invariably work together this might not work and of course the visual aspect is confused by the smear factor that renders the blades invisible to a flying bird.

Being unable to see or hear the blades represents a very real danger and probably explains the high mortality rate at wind farms sited in frequently used flight or migration paths. The down draught and turbulence caused by the wind passing through the blades also plays a part in disturbance, injury and death rates.

Under the UK Department of Trade and Industry Sustainable Energy Programmes a report was commissioned and first published in 2001 assessing the effects of noise and vibration from offshore wind farms on marine wildlife[33].

No similar report exists covering these effects upon land based wildlife as presumably it was not considered that detrimental exposure would be caused by clearance and site preparation or the operation of wind turbines on land, even if close to freshwater sources containing aquatic creatures. Generally it seems for land sites an ecology statement is produced by the proposed developer either voluntarily or more frequently in the form of an Environmental Impact Statement.

There are however some interesting observations contained in the marine report that could equally or partially apply to fresh water fishes and invertebrates starting with the generic impacts of building a wind farm and these are:

- Characterisation of noise and vibration generated by (offshore) turbine operation and construction activities.
- Propagation and attenuation of noise and vibration above and below the surface.
- Prediction of noise levels (at the shoreline) and impacts on (marine) wildlife.
- Likely range background noise above and below the surface.
- Identification of noise sensitive (marine) species most at risk to noise and vibration impacts related to UK (offshore) wind farms.
- The effects of noise and vibration on (marine) species.
- The extent to which (offshore) wind turbines may provide physical protection and new habitat opportunities.

The site sizes were to be restricted to 10km^2 and contain up to 30 turbines on each with a minimum output of 20MW (assumed generating capacity rather than actual production).

In summary the report concludes that ocean noise from wave, wind, rain and so on is produced across a very broad array of frequencies ranging from 1Hz – 25Hz with source levels up to 100dB. (They do not state whether this source was air or water bourn or a mix).

[33] ETSU W/13/00566/REP – University of Liverpool, Centre for Marine and Coastal Studies etc.,

It confirmed noise and vibration from human activities in the ocean are generally mid-low frequency between 10Hz and 1000Hz from such things as shipping, transportation, dredging, construction, hydrocarbon and mineral extraction, geophysical survey, sonar, explosions and ocean science studies.

Furthermore these operations may have very high source levels e.g. geophysical and seismic surveys at over 200dB and are both of brief (transient) or long (continuous) duration with generation including pulse, explosive or drilling. Wind farm operation noise is expected to fall within the ‘continuous’ category.

This is interesting because the range of noise and vibration and many of the sources would also apply to erecting and operating large land based wind turbines and could easily impact upon inland creatures, particularly fresh water fishes.

With regard to fish the report indicates they produce underwater sounds through stridulation (rubbing together body parts) and manipulation of the swimbladder, with frequencies produced ranging from 50Hz to 5kHz and source levels of up to 140dB. Whilst admitting that the sounds produced by many fish are not fully understood the report postulates that stridulatory noises are thought to be associated with alarm and resonant swimbladder sounds may play a role in social communication.

Clearly the noise from wind turbines has a frequency range coinciding with those made or utilised by fish and the report admits this overlaps with the sensitivity thresholds of many fish and some of the larger marine mammals. Reference is made to information taken from the study of an offshore wind farm at Svante, Sweden where the estimated peak noise was 120dB at 16Hz and mentioned some effect may be apparent on species such as cod.

One of the report conclusions is that due to the lack of available studies into the effects of offshore wind farms upon mammal, fish and migratory fish behaviour and ecology further monitoring is needed and additional studies required.

Nevertheless mention is made of other studies concerning fish (and these are not named) showing that noise in general, such as that associated with shipping, causes avoidance that can lead to change of migration routes, feeding and spawning areas. Obviously an inference that arises is if this occurred at sea then similar general noise could affect fish within pockets of landlocked water. Unfortunately having less room to take avoiding action might have greater adverse consequences.

The report also avers to the lack of study describing the impacts of noise on invertebrates and planktonic organisms but suggests the general consensus is that there are very few effects, behavioural or physiological, unless the organisms are very close to a powerful noise source.

This seems rather a summary dismissal of what could be a significant effect by noise from turbines upon important levels in the food chain. Presumably peak noise sources of 120dB are not deemed ‘powerful’, which maybe true when compared with airguns at >200dB, but would surely still be considerable when up close?

A couple of intriguing aspects arise in the report summary. The first suggests that as well as fish taking avoiding action when confronted by constant noise some also seem attracted to the source. Whether this is because of disorientation or simple curiosity is not discussed. Possibly they believe the sound has uncovered a fresh food source, as this must surely occur following a heavy storm or even tremors and the like from earthquakes.

The second intrigue is that building and inserting a number of large wind turbines into the sea could create new habitat for wildlife from artificial reefs. Likewise perhaps on land except here it would be a change of land use beneath the turbines as opposed to creating constructions for the adherence of barnacles and the like.

Apparently fish tend to congregate around objects placed in the sea although the report says the reason is poorly understood and it is postulated they are attracted as submerged objects provide shelter from currents, wave action and predators. Another reason maybe weed growth containing food sources.

Oilrig platforms seem to act as a magnet for some creature species despite noise from pumping operations. Possibly wind turbines in the sea would act similarly, although it appears a higher level of more or less continuous noise may be somewhat of a deterrent. Only time and study will confirm one way or the other.

Interestingly Beulig (1982) demonstrated that sharks are attracted most readily by broad-band, low-frequency, irregularly pulsed sounds of 20-100 Hz. To investigate the possibility that sharks are attracted to biologically significant sounds (such as accelerating schools of fish, injured and struggling fish, and feeding animals) that exist in the frequency range below 20 Hz, Beulig measured the responses of juvenile lemon sharks (Negaprion brevironstris) to low frequency (12.5 Hz), irregularly pulsed sounds.

The sharks were born in captivity and deprived of normal prey-capturing experience and social interaction with wild sharks. Initially, the juvenile sharks, tested individually, were not attracted to the low-frequency sounds, even after opportunities to capture living prey and to experience auditory stimulation associated with wounded, struggling fish were provided.

When the sharks were tested in groups of three, their approach-response level indicated attraction to the low-frequency sound and results compared favourably with juvenile sharks that had species-typical feeding and rearing experience. Thus, the existence of a social factor in response to sounds was verified.

Mindful of the current intention to place a large number of wind turbines in the shallow seas surrounding the coastline of Great Britain coupled with increased sightings of various shark species in coastal waters one wonders where this might lead.

Motor, Rail and Air Traffic including Sonic Booms

How noisy is a large lorry? This will depend upon many factors including weight and type of load, whether the vehicle is under stress climbing a gradient, which gear is being utilised, what type of road surface it is travelling on and where the receiver of the noise is situated in relation to hearing the sound.

Road traffic by its very nature does not stand still for long. The noise of a single vehicle is therefore not necessarily as critical as the volume of traffic and frequency times. Naturally limiting the noise of individual vehicles at the point of manufacture will assist in reducing the combined sounds from a large number travelling in streams or convoys.

The European Parliament set a noise limit for heavy lorries that was introduced by the European Community in 1992. The level agreed was 80dB(A) across the board although some individual countries opted for slightly differing arrangements, such as Austria where a night travel (10pm – 5am) ban already applied to lorries on motorways unless exempt. Here the exemptions set a limit of 78dB(A) for lower powered lorries and 80dB(A) for the larger variety.

This Parliament also set limits for cars at 77dB(A) falling to 74dB(A) after 1996 and for motorcycles to be reduced in stages. Since 1994 the levels for two wheeled motor vehicles have been 75dB(A) for machines up to 80cc, 77dB(A) for those between 80cc -175cc and 80dB(A) for those above 175cc.

The various levels have been adopted by the UK and under Planning Policy Guidance 24: Planning and Noise, these levels have been used to assist in determining the acceptability thresholds to be used by planning authorities when considering the effects of noise from roads on new dwellings.

A table has been created within PPG24 that also embraces noise from air traffic and railways (large diesel trains are known to emit low frequency sound and infrasound in the range of 8Hz to 100Hz not only from the engine but also through air displacement such as when entering a tunnel).

In creating the table four noise exposure categories (NEC) were compiled and should be read in conjunction with the table. They are as follows: -

A. Noise need not be considered as a determining factor in granting planning permission, although the noise level at the high end of the category should not be regarded as a desirable level.

B. Noise should be taken into account when determining planning applications and where appropriate conditions imposed to ensure an adequate level of protection against noise.

C. Planning permission should not normally be granted. Where it is considered that permission should be given, for example because there are no alternative quieter sites available, conditions should be imposed to ensure a commensurate level of protection against noise.

D. Planning permission should normally be refused.

Each of these categories is for guidance only and the method of arriving at the levels is explained in the PPG24 document. The sound levels are shown in dB(A) terms. Moreover it suggests in some cases local planning authorities may be able to justify a range up to 3dB(A) above or below those recommended. The noise exposure categories (NECs) are as follows: -

	Noise Exposure Category (NEC)			
Noise Source and Hours Applicable	**A**	**B**	**C**	**D**
Road Traffic				
07.00 – 23.00	<55	55 – 63	63 – 72	>72
23.00 –07.00	<45	45 – 57	57 – 66	>66

Rail Traffic	**A**	**B**	**C**	**D**
07.00 – 23.00	<55	55 – 66	66 – 74	>74
23.00 – 07.00	<45	45 – 59	59 – 66	>66

Air Traffic	**A**	**B**	**C**	**D**
07.00 – 23.00	<57	57 – 66	66 – 72	>72
23.00 – 07.00	<48	48 – 57	57 – 66	>66

Some interesting points arise out of reproducing these 'recommended' levels.

- On face value the unacceptable thresholds in category 'D' are all much lower than the recognised sound of a single 1.3MW wind turbine.
- The tables and explanatory notes within the content of PPG24 do not explain how far away from the noise source the measurements should be taken, relying presumably upon the developers and local authority to apply discretion.
- With aircraft noise the levels relate those at 1.2metres above open ground.
- The notes state that specific industrial noise levels should not be assessed by use of the tables but can be considered if contained as part of a noise mix as long as it is not the dominant noise.
- No reference is made to measurement of infrasound or low frequency sound as a separate entity.

Once more it seems reasonable to conclude that where noise levels are unacceptable for humans they must be at least equally unacceptable to other creatures exposed to such disturbance.

Brattstrom and Bondello (1983) found that off-road vehicle (ORV) noise affected hearing physiology of the desert kangaroo rat (Dipodomys deserti). Peak SPL's measured for ORV's varied from 78dB to 110dB. Dune buggy sounds were played to the animals through an amplifier to produce a sound pressure level reaching 95dB. The kangaroo rats suffered a temporary threshold shift in their hearing sensitivity. At least 3 weeks were required for their hearing thresholds to recover. Because the ears of kangaroo rats possess anatomical adaptations to promote amplification of low-frequency sounds, the rats have little means of preventing full amplification in their ears of high-intensity, low-frequency sounds of dune buggies. This could seriously affect their ability to avoid approaching predators.

Low frequency noise and infrasound effects from motor traffic upon dairy stock would presumably have an impact on milk yield and quality if subjected to frequent exposure. The following two noise experiments are revealing.

Tractor engine sound at 97 dB significantly increased the glucose concentration and leukocyte counts in the blood of dairy cows and markedly reduced the level of haemoglobin (Broucek et al. 1983).

Although not using LFN or infrasound another experiment using a tone of 1,000 Hz (l10dB) resulted in a significant increase in circulating glucosea, nonesterified fatty acids, and creatin; a significant decrease in haemoglobin; and a slight decrease in thyroxin in plasma.

High glucose level is a recognized response to stress, in this case, probably sounds. The accompanying responses were also the result of stress, and part of the neuroendocrine stress reaction. For example, release of thyroid stimulating hormone (TSH), known to affect growth rates, can be inhibited by negative feedback from adrenocortical hormones after a stress response.

Noise from road traffic does include both low and high frequencies. Vehicle movement and rate of recurrence probably cause as much disturbance to wild life as the sounds emitted. Road kill from impact is a serious cause for concern so if further harm is being caused through noise exposure the concern increases.

The foremost difficulty in summarising the effect of road noise on wildlife is the lack of concentrated studies that have directly addressed the problem. Most have been concerned with collision damage, eradication or destruction of habitat and severing of commuting routes.

Background noise from roads ranges from almost ever-present in respect of busy thoroughfares, regular but intermittent on less frequently used roads and occasional elsewhere. Each category brings its own problems.

Constant noise raises the ambient levels and could affect creatures because of the masking effect. Less frequent but regular sounds might create just enough habituation as to be dangerous and occasionally (such as in country lanes) lull creatures from hiding at lethal moments.

Road verges can act as small havens for wildlife such as butterflies and an increase in voles and field mice on motorway embankments has seemingly led to more kestrels using these areas as feeding habitats apparently oblivious to the noise and movement of traffic. Conversely a study in America showed a decline in species variety of aquatic insects in watercourses and ponds near to roads with an increased volume of traffic. Noise is believed to have played a part but the absolute cause was not determined.

On the other hand roads can act as barriers to both non-flying and flying insects. Certain beetles have declined where roads dissect their habitat. Noise, exhaust and salinity were found to be the causes. Similarly orange tip butterfly were effectively barred from crossing a large road carrying 40,000 vehicles a day, although it is not known for certain if noise played a part.

Birds and song birds in particular have to discriminate between their own and other species calls and songs. This need is an important aid to communication for mating, group bonding, feeding, danger awareness, flocking and at the other extreme, isolation for territorial requirements. Traffic noise can mask the effects of songs and calls.

Estimates have been made that bird song will attenuate at the rate of 5dB per metre for a bird 10metres above ground in an open field to 20dB per metre for a bird on the ground in a coniferous forest. Therefore any high volume noise of a virtually permanent rate, such as that caused by continuous rates of flowing traffic on a busy highway could mask attempts at communication. (Reference has already been made to similar masking by wind turbine noise).

In the Netherlands studies have been made of the effects of road noise upon some birds. Reijnen and Foppen, 1997 studied willow warbler (Phylloscopus Trachilus) and found the density of territorial males was lower at 200metres from the road than at greater distances (up to 400metres). Also, older males were more abundant further from the road. It is suggested that noise may have an important effect (predicted to have a mean of 50dB (A) at 500metres along the highway and traffic density of 50,000 vehicles a day). The dispersal of breeding males along the road was broken down subsequently into progressively increasing in zones 0 – 200metres, 200 – 400metres and a >400metres control zone.

Another study by Reijnen and Foppen in 1998 covered a variety of bird species and found 17 of 23 species studied for three years showed some negative effect of road noise (reduction in numbers) and another twelve species of passerines were found to reduce in grassland close to a busy road. Road noise of 50dB was found to be most significant at 100metres from the road and was measured at 70dB on the verge at roadside. At a density of 5,000 cars a day the reductions for most species were 12% - 56% at 100metres distance.

At distances of >100metres only the black-tailed godwit (Limosa limosa) and oystercatcher (Haematuras ostralegus) showed reduction in density. At a traffic density of 50,000 cars a day bird density was reduced 12% - 52% for all species studied up to 500metres distance. Sensitive species including waterfowl, lapwing and skylark were reduced in density between 14% and 44% up to 1500metres.

A more extensive study of 43 species of woodland birds in both deciduous and coniferous forests found that 26 (60%) showed some reduction in density adjacent to the road. Noise was the only factor found to be a significant predictor and the number of cars and distance from the road were significant factors in the number of breeding birds.

The "effect distances" were 40metres -1500metres (10,000 cars/day) and 70metres -2800metres (60,000 cars/day). There was a reduction in density at 250metres from the road of between 20% and 98%. The frequency range of road noise was 100 Hz to 10 kHz with the loudest in the range of 100-200 Hz and 0.5-4 kHz with a threshold at between 20dB (A) and 56dB (A). The authors note that if noise were constant there was no difference between plots with high and low car visibility.

It should also be noted that a supplementary aspect for the reductions was thought to be stress brought about by the noise and movement of the vehicles. Furthermore a similar study in the USA supported the findings and commented that mammals (moose and deer), amphibians as well as some species of grassland and forest birds were all affected at distances of >100metres from the roadside when traffic levels were increased to 15,00 – 30,000 cars a day. Both presence and breeding of birds was reduced up to 700metres and with more than 30,000 cars a day presence and breeding was reduced up to 1200metres away.

Quite clearly low frequency noise played a significant role in creating bird disturbance/displacement and was sufficient to cause a serious reduction in breeding numbers in the study areas. Assuming similar habitat was within reasonable distance without interference from road noise then after initial displacement successful breeding may have been achieved elsewhere. Severe problems could arise if not.

In a nocturnal species (the stone curlew, *Burhinus oedicnemus*) in England, roads were found to reduce numbers at distances of up to 3 km. The authors suggest that visual stimuli (headlights) could have a greater effect than noise alone even though traffic noise or vehicle movements are suggested as primary causes. It should be noted that, in this study there was no evidence of a lessening of the effect if nearby suitable habitat (away from the road) was scarce or abundant.

Gutzwiller and Barrow studied birds in a Chihuahuan desert and found the abundance and species richness within 21 of 26 species to be reduced and that significant predictors were (generally) being within 1-2km of the nearest road as the length of road increased, distance to the nearest road, distance to the nearest development or a two-way interaction of these variables. It is important to note that landscape factors in conjunction with the road factors were found in many models to be significant (e.g. distance to nearest development, areas covered by different types of vegetation). The traffic density was reported to be between 407-459 vehicles/day with a speed limit of 45 mph. The noise levels were not measured; however, the effect is postulated by the authors to be related to the roads or the associated development.

Noise carries many properties with it including the number, size and speed of vehicles. The noise levels were about 59 dB(A) adjacent to roads and 38 dB(A) in remote areas with a threshold for response of between 27-61 dB(A).

The general conclusion is that some (although not all) bird species are sensitive at least during breeding to noise levels and that the distances over which this effect is seen can be considerable varying from a few metres to more than 3km.

Unlike birds some mammals tend to have more tolerance of road presence and presumably the associated noise. This may depend upon the timidity of the species, nocturnal habits or be due to the lack of need to communicate at the same level as birds.

In country districts badgers, deer and foxes are regularly killed crossing or using the roads. Squirrels and other small mammals also regularly become victims of vehicle collision, however it appears this mainly occurs on roads with relatively low volumes of traffic. Motorway victims mainly occur at night when traffic is lighter. Consequently it could be assumed that in general mammals avoid roads during periods of heavy motorist usage i.e. when noisiest.

In a study of elk movement along interstate 80 in Wyoming (USA) the traffic noise was recorded as an average of 54dB(A) - 62dB(A) for cars and 58dB(A) - 70dB(A) for trucks with little evidence of avoidance up to distances of 300 yards. At the same time there did appear to be a physical barrier imposed by the road. Adams and Geis reported that elk generally avoided roads while deer showed little difference in distribution around interstate highways (monitored at distances up to 400metres from the road).

Road traffic is forever increasing, but air travel is rapidly escalating as well. Some studies have been carried out aimed at reducing strike and kill rates on birds at airports. Most have experimented with noise scaring, which suggests the presence of aircraft noise alone may not deter birds or have a detrimental effect upon them.

Military planes however may have different consequences. A review of the effects of aircraft noise and sonic booms on domestic animals and wildlife was conducted in the USA in 1988 (See Footnote [21]). This report differentiated between both types of noise and commented as follows: -

"Differences in noise from low-altitude subsonic over flight and high-altitude supersonic over flight include the increased duration of noise from a low-altitude over flight, the greater probability that noise from low-altitude over flights will be accompanied by visual perception of the aircraft, and the broad-band frequency distribution of jet engine noise (about 200Hz -20,000 Hz) versus the low-frequency noise of sonic booms (with most of the sound energy between 15Hz -50 Hz)."

The jet engine noise commences in the low frequency band level rising rapidly and steadily to a crescendo passing through the upper limits of defined low frequency noise (400Hz – 900Hz) to peak levels in the higher frequency range at around the upper limit of human hearing (20,000Hz). Whereas the 'sonic boom' occurs as both infrasound and low frequency noise, but is contained within a much narrower bandwidth where some of the 'noise' is below the threshold of normal human hearing (16Hz - 20Hz).

These levels of frequency are particularly significant as not only are they emitted at a high dB rate (130dB and above) they also occur across bands that fall within the known hearing ranges of most domestic and wild creatures inhabiting both the land and fresh water. Indeed the dB figure given in the above report is 140dB for a jet aircraft taking off at 25metres distance – considerably above the accepted human pain threshold (120dB).

We have already established that animals rely upon hearing to avoid predators, to obtain food and to communicate and thus it has been a determining factor of their evolutionary behaviour. Producing sound does not necessarily mean an animal has a well-developed hearing range. Conversely having 'good' hearing does not always go in tandem with vocal ability. A horse for example has a limited vocal range within a bandwidth of 50Hz – 100Hz but can hear sounds across a spectrum of 55Hz – 33,500Hz.

Vocal communication plays an important part in the social interaction of many creatures and the imposition of noise from man-made sources could potentially disrupt the ability of species to communicate or introduce new and possibly disturbing behavioural factors into social groups. (See the squirrel behaviour under the wind turbine section). Tolerance of noise has also to be considered when evaluating the effects upon wildlife.

Aircraft noise (as with other sources) has the potential to mask sounds produced by creatures as they endeavour to communicate thus possibly affecting mating sequences, predator warning or frightening off prey. These are direct affects but secondary impingements could include stress and detrimental changes reducing or eliminating the ability to find water, food and protective cover.

Timing of noise disruption may also play an important part. Night noise might disrupt sleeping patterns. Seasonal noise may disrupt migration thus influencing physical condition resulting in debilitation and have a chain reaction upon other species that are interdependent upon their well-being.

Animals appear to be more sensitive to noise disturbance than humans (Borg, 1981). Possible harmful effects of sound may also relate to the noise content leading to risky actions or as mentioned previously, masking, thus obscuring significant intelligence that otherwise would be gleaned as a safety factor, rather than the actual superimposed sound.

Jet noise and sonic booms are by their very nature often sudden, unexpected and extremely loud. Alarm precipitates nervous reaction, an injection of physiological stress and invariably leads to instinctive flight. Occasionally the reaction is one of combat where the noise source is seen (heard) as a threat to dominance and a creature might consider standing its ground and take up a fighting stance.

Either way stress factors are induced that activates the neural and endocrine systems leading to increased blood pressure and changes in glucose and cortisone levels. Prolonged exposure to severe stress can lead to death. Continuous high-level noise is therefore potentially a severe environmental pollutant.

Sonic booms however are not continuous and should be categorised as occasional sources of disturbance unless the area is a specific military testing ground where frequency would be greater. Generally such noise would be spasmodic and studies (Bell, 1972 and Milligan et al, 1983) indicate that animals are startled by both sonic booms and subsonic low altitude flight. Birds appear to more affected than mammals and sometimes some of the latter adapt to the disturbances. Reactions however are never seemingly predictable but appear similar to those created by other comparable noise sources such as helicopters.

Aircraft noise and sonic booms have been 'blamed' for reduction in egg laying by domestic poultry. Tests (unnamed) mentioned in the Manci Report (Footnote [21]) suggest field studies on animals indicate that reproduction of wild populations may be more affected by noise disturbance than domestic populations. The reproductive effects have primarily been the result of disturbance of the animal's behaviour during the reproductive cycle.

The use of military aircraft at supersonic speeds resulted in some successful claims for damages following alleged injury or loss involving livestock (Ewbank, 1977) and prompted investigation into noise effects on domestic farm animals including the physiological effects of aircraft and non-aircraft noise on dairy cows, goats, pigs and sheep.

Previously a variety of tests recorded differing findings. For example one of the earliest studies of noise effects on cows was an attempt to determine the relationship between the nervous system and the ejection of milk of three Jersey cows at the Kentucky Agricultural Experiment Station (Ely and Peterson 1941).

Nerves were immobilised in the left half of the udder of each cow. After recovering from surgery, all three cows began ejecting milk normally. The desensitised half of the udder was able to eject milk just as well as the intact half. 0ne cow was then subjected to various experiments to determine the effect of the nerve supply to the glands under various conditions, such as fright caused by loud noises.

Fright was induced by exploding paper bags every 10 seconds for 2 minutes just prior to attaching the mechanical milking machine. This resulted in an immediate cessation of milk production. Thirty minutes following exposure to exploding paper bags, 70% normal milk production occurred. No difference in response between the two halves of the udder was observed.

Injections of adrenalin gave similar results. The amount of adrenalin injected appeared to determine the length of time needed before natural milk ejection resumed. Presumably, this length of time would be proportional to degree of fright. Fright, such as that caused by a loud sound, could stimulate the natural production of adrenalin.

Parker and Bayley (1960) studied the effects of jet aircraft noise and flyovers on milk production of dairy herds located near existing air bases. Data for 12 months were compiled on the daily milk deliveries of 182 herds located within 3 miles of eight Air Force bases. Although data were lacking at some bases, results of this survey showed no evidence of effects on milk production resulting from jet over flights or proximity to an air base. Milk yield of dairy cows in an area of frequent sonic booms, Edwards Air Force Base, California, was also similar to the yield of control dairy cows; however, the animals had been previously exposed to at least four to eight sonic booms per day prior to data collection (Casady and Lehmann 1967).

Bond et al. (1974) found no evidence that simulated sonic booms had any effect on eating patterns, total feed intake, or rate of feed intake in dairy cows. However, Kovalcik and Sottnik (1971) found that a noise level of 80 dB (unspecified scale) increased feed intake and the rate of milk-releasing indices, but did not affect the milk yield of dairy cows. (The everyday noise level of the animals' surroundings was 50-60 dB.) Kovalcik and Sottnik (1971) presumed that the noise level of 80 dB was within the limits of the normal tolerance of the animal. When these same animals were exposed to a sudden high-intensity noise (105 dB), feed consumption was reduced as well as milk yield and rate of milk release. The authors found, however, that if the noise is increased gradually, instead of suddenly exposing the animals to the high-intensity noise, the response is not as negative.

Later, Cottereau (1978) stated that simulated sonic booms had no effect on semen quality or quantity of bulls at an artificial insemination centre. Pregnant Charollais cows exposed to 20 simulated sonic booms during the first month of pregnancy gave birth to normal calves. The intensity and frequency of the booms was not described.

Other farm animals however, have shown to be adversely affected. Noise (including jet noise) reduced the milk yield in all five goats used in an experiment (Sugawara et al. 1979). The noise had a greater effect on milk yield within the first 3 months after parturition. Sugawara et al. (1979) suggested that intermittent exposure to noise had a greater effect than continuous exposure. This would seem to be a significant insofar as it may support other suggestions of tolerance to constant noise at certain levels as opposed to sudden noise at varying intervals. (The bird scaring device syndrome).

Pigs exposed to 120dB sound for 6 hours showed an increase of plasma 11-OH-corticosterone and catecholamines (Borg 1981). Exposure to 108dB engine sound for 72 hours resulted in a decreased corticosteroid level, followed by an increase immediately after the stimulation ceased. This biphasic response may indicate a negative feedback effect on the anterior pituitary, which is responsible for releasing ACTH that activates the adrenals during stress. Sound exposure, at least short-term, influences several hormonal systems of pigs.

Excess secretion of hormones from the adrenals, water retention, and sodium retention were observed in castrated male pigs exposed to 93dB (unspecified frequency) continuous noise over several days (Dufour

1980). Excess aldosterone may be induced by stress, resulting in the upset of the electrolyte balance, which can be manifested by hypertension (possibly due to sodium and water retention), excessive urination, and thirst (Dufour 1980).

Only a few studies of the physiological effects of noise on rodents have involved wild animals. A field study by Chesser et al. (1975) involved two populations of house mice near the end of a runway at Memphis International Airport. Adult mice also were collected from a rural field 2.0km from the airport field. Background noise levels at both fields were 80dB-85dB. Noise levels of incoming and outgoing aircraft at the airport field averaged 110dB, with the highest reading reaching 120dB.

Total body weights and adrenal gland weights of mice from the fields were measured. Additional mice were captured from the rural field, placed in the laboratory, and exposed to 1 minute of 105dB recorded jet aircraft noise every 6 minutes to determine if noise was the causative factor. Control mice were not subjected to noise. After 2 weeks, the adrenals were removed and weighed. Adrenal gland weights of male and female mice from the airport field were significantly greater than those of mice from the rural field.

The noise-exposed mice in the laboratory study had significantly greater adrenal gland weights than the control mice. After ruling out stress factors, such as population density, Chesser et al. (1975) concluded that noise was the dominant stressful factor causing the adrenal weight differences between the two feral populations.

A study was conducted on Mitkof Island, Alaska, in 1970 to determine the effects of real and simulated sonic booms on late pregnancy, parturition, early kit mortality, and subsequent growth to weaning of farm-raised mink (Travis et al. 1974).

The study involved 350 yearling and 148 2-year-old females and their progeny (1,845 kits). Treatment animals received either three real sonic booms (averaging 294 mN/m^2 overpressure) or three simulated sonic booms (averaging 167 mN/m^2) on the day approximately 40% of the females in each group had whelped.

Booms occurred over a 60-minute period; the second boom was 45 minutes after the first, and the third was 15 minutes later. The booms caused transient structural vibrations of $10m/sec^2$ or less on the wooden nest boxes. Mean length of gestation, mean number of kits born alive per female whelping, mean number of kits born alive per female, and mean weights of kits at 49 days of age were similar among treatment groups and the control group.

The observable behavioural reaction of female mink exposed to real or simulated sonic booms was brief and had no apparent long-term effect on the health and well-being of the females and their newborn kits. Most mink returned to pre-boom activities within 2 minutes after each boom and appeared to habituate to the acoustic stimuli and vibration of sonic booms after exposure to only three booms in the span of 1 hour. No panic behaviour, packing of kits, or killing of kits was observed during the boom tests.

During 1973-1974, the Federal Aviation Administration (FAA) studied the effects of sonic booms on the environment during routine U.S. Air Force super-sonic acceptance test flights of F-111 jets southwest of Fort Worth, Texas (Higgins 1974).

The behavioural response of songbirds in an oak wood to F-111 flyovers was noted in one instance. The jets flew over the observation area at 20,000-41,000 ft at Mach 1.0-1.55; peak overpressure values at the site were measured at 0.55-3.25 psf (mean = 1.15).

The continuous songs of birds were completely silenced 4-8 seconds before the arrival of the audible sonic boom. Further study disclosed that this response of songbirds coincided with the arrival of the seismic signal propagated through the ground and preceding the sonic boom shock wave by 4-8 seconds.

This difference in the arrival times of the audible sonic boom and the seismic signal was caused by the greater velocity of the seismic compression wave signal transmitted through the dense earth medium ahead of the audible atmospheric sonic boom shock wave advancing over the Earth's surface at a speed equal to the ground speed of the supersonic aircraft generating the sonic boom.

The observation that songbirds were alerted to the seismic compression waves preceding sonic booms helps explain phenomena described in historical tales and literature regarding a "hush or stillness falling over" an area preceding some remarkable event, such as a volcanic eruption, explosion, or earthquake at sea generating a tidal wave.

When the sonic booms were audible, the songbirds uttered "raucous discordant cries" for a few seconds. Within 10 seconds after the audible boom, the songbirds were singing their "normal songs."

Davis (1967) noted the response of a population of ravens (Corvus corax) to a sonic boom in central Wales. Three or four ravens were idling in the up-currents over a high rock spur between two streams. When the silence was shattered by a "very loud sonic bang as a jet aircraft passed overhead," Davis (1967) heard ravens calling agitatedly and saw small groups flying from all directions and converging over the crest of the spur. In about 5 minutes, 62-70 ravens were present.

They were flapping, soaring, and chasing each other, and often settled briefly on the rocks, with a great deal of noise. Ravens from at least 2 or 3 miles around may have been involved. Within 10 minutes, they started to disperse again, and calling died down considerably. About 30 ravens were still soaring over the hill when Davis (1967) left the area, an hour after the boom.

Mobile Telephone Masts

The introduction of mobile technology and in particular the public adoption of cellular telephones has attracted a great deal of media comment. Despite their popularity it seems concern is felt over the prolonged use of the handsets because of radiation emissions close to the brain and the signals conveyed by the transmission equipment attached to masts.

According to the Mobile Operators Association (MOA) radio base stations receive signals from mobile telephones – which are low powered two-way transmitters, and transmit them to other mobile or fixed networks. Commonly called ‘masts’, their antennas can be attached to a freestanding mast or existing structures such as roof tops or water towers.

Base stations have to be placed quite close together otherwise because the signal strength is weak, gaps appear in the ability to receive or make calls. They are also required where customers need coverage. Hence in built up areas the masts are placed about 200m – 500m apart and 2km – 5km apart in rural areas.

There are currently about 47,000 base station sites in the UK, with two thirds of these on existing buildings or structures. With around 62.5million mobile phone subscriptions in the UK and new technology being added all the time, more base stations will have to be built and by 2007 it is possible there will be 50,000.

Many of the base stations use microcells, especially in busy areas and are usually mounted at street level on external walls, lampposts or neon shop signs – often disguised as building features. These microcells have lower radio wave outputs than the larger base stations.

The signals emitted by the ‘masts’ are of a low frequency nature and operate in pulses. A newspaper article[34] reported that health fears about mobile phone masts centred on information claiming signals were transmitted and received on the 400MHz frequency, which pulsated at 17.65Hz. In 2000 the UK Government report on mobile phone safety by Sir William Stewart, a former chief scientific adviser, recommended that frequencies around 16Hz – frequency at which the human brain transmits signals – be avoided as a precaution, even though there was no confirmed health risk.

[34] The Independent: 23.11.2004 “The Mast Crusaders”

There are many operators of mobile technology and masts are shared where practicable. This slightly increases the levels of emissions although different operators might transmit at different power levels, frequencies and at different antenna height and direction. Shared sites are checked and certified for compliance with the international health and safety public exposure guidelines. Emissions are always said to be many times lower than the set 'safety' limits.

The cumulative effect might give rise for concern, although operators maintain they ensure compliance with public exposure guidelines. Radio waves decrease rapidly with distance. Approximately each doubling of distance reduces the field by a quarter. Antenna can be within a few metres of each other in the public domain and are said not to raise exposure levels anywhere near the guide limits.

Operators design safety zones around shared antenna sites. They assume worst-case conditions for maximum power levels. Audit of these sites by the Office of Communications (Ofcom) has not so far uncovered any (from around 500 tested) where the levels of emissions exceed the safety levels.

Just as with other sources of low frequency noise or infrasound it has been quite natural for all reports and information to focus upon the effects upon humans. Questions do arise however insofar as impact on other creatures is concerned. For example, as shown above pains are taken to ensure the majority of transmission masts are placed above street level, not only for better reception but also to ensure the emissions are not constantly affecting the public. Birds however frequent the masts and spend a lot of time nesting, perching, roosting and flying at heights that must directly correspond with the beams of emissions.

The house sparrow is in decline within some city areas, particularly London where it has disappeared entirely from some previously common haunts. This bird has been shown to have an absolute sensitivity to sound pressure level at –8.31dB SPL and detect low frequency sound of 0.29kHz.[35] Elsewhere in this report it has been stated that birds generally hear best at frequencies between about 1hZ and 5hZ.
Could the 'unheard' frequency at which the emissions from masts are transmitted and received be detected by the sparrows and cause them sufficient distress or alarm to abandon their habitat? Perhaps it is not a coincidence that this species is thriving in many rural areas where mobile phone masts are further apart and less numerous.

Studies are ongoing into the decline of the sparrow and a number of suggested reasons have been advanced for the reduction in numbers including, lack of food, particularly aphids, which are fed to nestlings, possibly through the use of unleaded petrol, cat and Sparrow hawk predation, reduced nest sites and cleaner streets thus less foraging opportunities. None of the published reports have mentioned low frequency sound.

One report by DEFRA[36] highlights the decline of the sparrow since the end of the 1970's with the main fall in the South East but with increases in Scotland and Wales. The greatest declines have been since the 1980's in suburban and urban gardens. Rural gardens being the most favoured habitat now. These facts coincide with the increase in technology producing low frequency noise and infrasound in built up areas, particularly from mobile phone masts. Clearly an investigation is needed, if only to dispel this suggestion as incorrect.

The DEFRA report states high nest failure rates have been recorded in the areas where population of sparrows is declining most rapidly, namely South East England. It is reasonable to surmise this is where the greatest proliferation of mobile phone antenna is based.

<u>High Voltage Cables (Power Lines)</u>
The National Institute of Environmental Health Services and National Institute of Health (Australia), 2002 completed a detailed explanation of the effects of power line radiation but did not mention anything about 'noise'. Electromagnetic transmissions however, are emitted at 50Hz or 60Hz and are audible. Sometimes a 'fizzing' effect is heard.

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[35] Avian Hearing and the Avoidance of Wind Turbines: R Dooling Ph.D June 2002
[36] DEFRA Status and population trends of the House Sparrow and Starling 2002

In general it seems the 'waves' produced by power carrying cables (either above or below ground) would need to fluctuate to provide a stimulus before being 'detected' by the human brain. Presumably this would also apply to other creatures.

Most sound waves from power lines are believed to be steady in nature and do not rise and fall sufficiently for the human brain to detect the changes as audible noise. Likewise any thermal effect from the electromagnetic energy produced is absorbed by body tissue, including the head and ear and would probably, occur at very high frequencies (200MHz – 10,000MHz).

Miscellaneous Sources

Studies involving a miscellany of noises are reproduced below and were taken from the report by Karen M Manci et al featured previously in these notes (See Footnote [21]).

The initial physiological responses to sound measured in sheep were heart rate and respiratory rate (Ames and Arehart 1972). Early-weaned lambs were exposed to three sound types:

(1) United States of America Standard Institute white noise
(2) Instrumental music
(3) Intermittent miscellaneous sound (IMS).

Each sound type was studied at two sound pressure levels, 75dB and 100dB. The IMS consisted of the following sounds: electrical and diesel engines, jet and propeller aircraft, roller coasters, stadium noise, fog horns, firecrackers, machine guns, cannons, rain, and band marches. White noise and music exposures were continuous. The control period was 21 days with a background noise level of 45 dB. Initial exposure to 75dB and 100dB white noise did not cause a change in heart rate in acclimated lambs. In non-acclimated lambs, initial exposure to 100dB white noise significantly increased heart rate. During the entire test period, non-acclimated lambs exposed to 100dB white noise had significantly higher heart rate than lambs acclimated at either 75dB or 100 dB.

Respiration rate for acclimated lambs was constant when initially exposed to 75dB, increased rapidly during the first hour, and peaked during the eighth hour. Non-acclimated lambs showed little change in respiration rate until the fourth hour, when a rapid increase occurred. After 8 hours of exposure to 100dB, both acclimated and non-acclimated lambs had significantly higher respiration rates than controls and lambs exposed to 75dB. This trend continued for the 12-day test period. Initial exposure to music at 75dB increased the heart rate. Acclimated lambs exposed to 100dB music had significantly higher heart rate over the 12-day period compared to lambs exposed to 75dB. Non-acclimated lambs had significantly higher heart rate than acclimated lambs subjected to both 75dB and100 dB. Non-acclimated lambs exposed to 100dB IMS had significantly higher heart rates than acclimated lambs; however, respiration rates were highest at 75dB.

Data presented in Ames and Arehart's (1972) study indicated that some physiological responses to sound were characteristic of those of the stress response (e.g., adrenally oriented responses and acclimation to the sound environment). A sudden change that startled an animal usually resulted in tachycardia through action of catecholamines, or bradycardia caused by vagal stimulation. Sound exposures also usually resulted in vagal stimulation, except for non-acclimated lambs exposed to 100dB white noise. Heart rate response varied less when exposed to music, which suggests that music is less stressful than other sound types. Responses apparently varied by sound pressure level and duration. Respiratory rate appeared to be dependent on sound type (continuous rise in rate during IMS exposure) rather than sound level, with a possible effect of intermittent play versus continuous exposure.

Arehart and Ames (1972) also determined the effect of sound types and intensities on growth and feeding efficiency on early-weaned lambs. Sixty lambs were exposed to the same three sound types and intensities (75dB and 100dB) of the above experiment. White noise at 75dB significantly increased the average daily weight gain and feeding efficiency. Acclimated and non-acclimated lambs subjected to 100dB white noise had significantly lower feeding efficiency, which was still higher than the feeding efficiency during the control period. Music at either intensity had no significant effect on performance. Lambs subjected to IMS noise consumed less feed per day than lambs exposed to 75dB white noise or music. Average daily gain in weight was significantly higher at 75dB compared to controls and 100dB IMS exposure.

The pooled data from Arehart and Ames's (1972) experiments indicated that intensity of sound significantly affected growth rate in early-weaned lambs. Again, music was less stressful than other sound types. The data also suggested that acclimation to sound occurred, with respect to daily growth rate. All non-acclimated lambs exposed to 100dB noise gained significantly less weight than lambs previously exposed to 75dB noise, suggesting that long-term study is needed to determine whether detrimental effects would actually occur during long-term feeding trials.

Harbers et al. (1975) studied the digestive response of yearling wethers to the same sound types and intensities used in the two studies above: white noise and music presented continuously and IMS. In control metabolism trials, sheep were placed in metabolism crates and exposed to 45dB background noise for 14 days. Dry matter feed intake was less when sheep were exposed to 75dB or 100dB of each sound type compared to controls. Type of sound had no effect on feed intake. Water intake and urinary output appeared to depend on sound type and not intensity. Sheep exposed to IMS consistently drank more water and excreted more urine than sheep exposed to continuous sounds, white noise, or music. If intermittent sounds are more annoying than continuous noise, this might explain why these lambs drank more water. Sound level, type, and the interaction of these influenced faecal moisture. Lambs exposed to 100dB music or IMS had less faecal water. Music at 75dB resulted in more faecal water excreted in those lambs, and less when exposed to 75dB white noise and IMS. However, faecal water was not related to water intake.

Exposure to IMS at 75dB and 100dB not only increased water intake, but also increased metabolizable energy of the ration and improved the apparent nutrient digestibility. Sound intensity did not affect apparent digestibility coefficients. The high digestibility coefficients for lambs exposed to intermittent sounds suggests that those types of auditory stimuli influenced the digestive system. This increased digestibility of feed, along with water retention, may partly explain the improved growth gain in lambs exposed to IMS. IMS increased metabolizable energy by 100 Kcal/day; no effect of intensity was observed.

Sheep probably acclimated to continuous and intermittent sound of 100dB or less. None of the sound stimuli seemed to adversely affect digestibility, with intermittent sound actually stimulating digestion. All of the above mentioned effects were short-term only. The effect of intermittent sound on long-term feed intake and digestibility should be investigated. The increased metabolic rate, had it continued, may have proved detrimental to the animal by shortening its life span or causing other physiological changes. Noise exposure above background level may play an important role in digestive efficiency, metabolic balance, and growth rate.

Thunder

Ogle and Lockett (1966) examined the effects on rats of recorded thunderclaps of 3 to 4sec duration, frequency range of 50Hz to 200Hz at 98dB to 100dB SPL, presented for 2 minutes out of every 15 minutes for 45 minutes. This was compared with effects from a pure tone of 150Hz at 100dB presented in the same sequence of time.

Urine was collected for analysis of sodium and potassium. Responses were compared among animals that were intact, that had denervated kidneys, and that had neurohypophyseal lesions. Thunderclaps increased the urinary excretion of sodium and potassium by intact rats but not by neurohypophysectomized rats.

Ogle and Lockett (1966) concluded that the thunderclaps produced emotional responses, and the pure tone did not. Thunderclaps affected the hypothalamus, resulting in excretion of oxytocin and vasopressin, which produced increases in sodium and potassium excretion with no increase in urine flow.

Other atmospheric and natural sources

The Krakatoa volcano erupted in 1883 intriguing scientists and others because of the sub audible sound waves they experienced thousands of kilometres away.

Modern equipment in the form of microbarometers can detect this type of infrasonic pressure movement and are also used to monitor nuclear test explosions and military type rocket firing.

In addition natural phenomena including earthquakes, tornadoes, landslides, aurora and meteors plus simple turbulence produce levels of infrasound that can be detected by sensitive recording instruments.

Driven by the cold war and commencement of nuclear test bans the need for monitoring increased to levels that required a network of sensors to be set up to probe the surface of the earth and the oceans as well as check for atmospheric movement.

This comprehensive coverage should produce information from listening posts that will help understand far more than manmade explosions. All unusual instances of infrasound should feature in the results and may even aid prediction of certain events or at least provide early warning of disasters such as a tsunami.

In some ways it seems we are playing catch-up with birds and animals as they often give early warning of disastrous natural events beforehand, albeit with only short notice. Unfortunately, unlike the old time miners utilising a canary to detect gas it is improbable that we will be able to harness this ability to good effect.

Chain saws and logging trucks

A study into road noise in America commented upon different sources of sound and the effects upon a variety of species including raptors. In one instance when referring to aircraft noise the report stated, "Chain saws were found to be more disturbing, although the average sound level was only 46dB(A). Grubb et al. reported that there was no discernable effect of logging trucks on breeding goshawk (*Accipter gentiles*) female or juvenile at a distance of 500metres. Noise levels were sporadic with peaks at 50dB(A) at a frequency of about 80Hz."

Plant and Appliances

A health study surveying human epidemiological effects[37]due to noise exposure in or near domestic buildings revealed a considerable number of factors with adverse effects from low frequency noise.

Noise measurements from plant and appliances were recorded and comparisons made between two groups of people. A test group was exposed to sound that included low frequency noise and the control group was exposed to a similar level of A-weighted sound level but had no LFN content.

There were quite substantial differences displayed in the levels of anxiety and other symptoms of distress between the groups after the exposure period. The test group suffered more annoyance, sleep disturbance and pain than the control group.

The dB levels were not particularly high but the adverse effects were significant as shown in the following tables:

Noise Exposure Table

Noise Source	L_AdB	Percentage of people exposed	Kind of exposure
Fans	26 – 31	33	Day, intermittent
Central Heating Pumps	23 – 33	18	Night, day intermittent
Transformers	20 – 23	30	Continuous
Refrigeration Units	21 – 32	19	Night, day intermittent

[37] Mirowska and Mroz, 2000

Symptoms Table

Symptom	**Test Group %**	**Control Group %**
Chronic fatigue	59	38
Heart ailments anxiety, stitch, beating palpitation	81	54
Chronic insomnia	41	9
Repeated headaches	89	59
Repeated ear pulsation, pains in neck, backache	70	40
Frequent ear vibration, eye ball and other pressure	55	5
Shortness of breath, shallow breathing, chest trembling	58	10
Frequent irritation, nervousness, anxiety	93	59
Frustration, depression, indecision	85	19
Depression	30	5

The marked increases in insomnia, shortage of breath and indecision, if repeated in animals exposed to similar levels of LFN might prove fatal. Lack of sleep would affect awareness, create lethargy and coupled with indecision be likely to hinder the ability of an animal to escape a predator.

This study appears to confirm the work of others investigating the effects of low frequency noise upon human behaviour (Persson-Waye et al., 1997. Persson-Waye and Rylander, 2001) where the findings in each case revealed the test subjects were not as happy, suffered reduced orientation, annoyance and disturbed concentration in comparison to the control groups.

Persson also found in earlier works (Persson et al., 1985. Persson and Bjorkman, 1988) that by comparing A-weighted noise levels the annoyance from the low frequency noise was greater than from higher frequency noise at the same A-weighted level and utilising dBA as a measuring scale underestimates annoyance for frequencies below about 200Hz.

Annoyance to humans would most likely manifest as disturbance insofar as wildlife is concerned thus stimulating the ‘flight or fight’ instincts. This could lead to bird nest abandonment, animals breaking cover or shelter and panic or aggressive behaviour amongst aquatic species that could not escape their environment.

The use of ‘A’ weighting is now considered inadequate for low frequency and infrasound noise assessment. ‘C’ weighting and ‘G’ weighting respectively should be used. (See: A Review of Published Research on Low frequency Noise and its Effects, May 2003 by Dr Geoff Leventhall et al).

The National Noise Incidence Study 200/2001 (United Kingdom)

This resulted in a report running to three volumes being published following a study of noise exposure based on 24-hour measurements outside a sample of 1160 dwellings in both urban and rural areas..

The findings denoted that allowing for 3% leeway either higher or lower, 54% of the population of the UK live in dwellings exposed to day-time noise levels above the World Health Organisation (WHO) recommended levels of 55dB $L_{Aeq.day}$. Similarly 67% (plus or minus 3%) of the population live in dwellings exposed to night-time noise levels above the WHO level of 45dB $L_{Aeq.night.}$

Noise was placed ninth in a list of twelve environmental problems with 84% of respondents reporting hearing noise from traffic and 71% noise from aircraft. 40% were bothered, annoyed or disturbed to some extent by road traffic noise.

The measurements were taken at 1.2m above ground and 2m away from the outside walls. As the majority of the noise seemingly originated from road traffic and aircraft it seems much of the content would include LFN and infrasound. The figures emphasise the astonishing extent to which noise is ever present and must surely be problematical to wildlife.

DISTRESS CAUSED BY DISTURBANCE TO WILDLIFE AND DOMESTIC ANIMALS
(Including infrasound and low frequency noise)

An Internet publication (Wildlands CPR) contains a synopsis of a lengthy paper written and submitted by D. J. Schubert as a petition against Off Road Vehicle use in U.S. National Forests. Extracts have been included in the following amalgam of comment upon animal suffering from human induced noise and general disturbance factors.

Distress (stress) is a consequence of disturbance, which can, if prolonged, cause substantial adverse impacts upon individual animals. Stress may be caused by both physical and psychological factors, but in either case results in physiological changes to the animals.

Exposure may be short or long term leading to acute or chronic symptoms. Hence a loud and unexpected noise may cause a bird to abandon a nest and/or young or persistent noise might drive an animal from a frequented habitat.

Off Road Vehicle (ORV) use for example, may cause both physical and psychological stress to a wide range of animals as a result of noise, pollution, activity patterns, and direct and indirect harassment or disturbance. The effects of recreation-induced stress, including lower reproductive output (Geist 1978), may not be evident immediately, but may appear days to years after disturbances (Gutzwiller 1991). Moreover, recreation-induced stress exacerbates the effects of disease and competition, leading to higher mortality well after disturbances occur (Gutzwiller 1991).

Birds are particularly prone to noise disturbance. Whilst not specifically commenting upon LFN or infrasound there is no reason to suppose the results from the following study résumés would be any different if the disturbance source included or resulted entirely from such causes.

In birds of prey, nesting failures (Boeker and Ray 1971), lowered nesting success (Wiley 1975, White and Thurow 1985), displacement (Andersen et al. 1986), and changes in wintering distribution and behaviour (Stalmaster and Newman 1978) were documented in response to human disturbance.

In their study of home-range changes in raptors exposed to increased human activity levels, Andersen et al. (1990) documented that increased military use in a site previously subject to low human use resulted in a shift in home range and activity areas for several raptorial species including red-tailed hawks, golden eagles, ferruginous hawks, and Swainson's hawks.

Additionally, the raptors increased the size of the area used and increased movements outside of the previously used areas, except during military use activities when several birds remained in isolated areas within their home ranges. Two birds, a ferruginous hawk and a Swainson's hawk completely abandoned the area not returning until the following spring.

Besides the obvious impacts of habitat abandonment, the changes in home range size, activity areas, and use of habitats; increased human disturbance may adversely impact upon an individual bird's energy budget, and productivity might decrease with subsequent impacts at the population level. If different raptor species demonstrate different levels of tolerance of human activities, in time continued human disturbance could result in a shift in the species composition in the area in favour of the more tolerant species (Voous 1977, Craighead and Mindell 1981, Andersen et al. 1990).

The physiological impact of stress on animals has been the subject of many studies, which have somewhat conflicting results. Selye (1950) suggested that an exhaustion of the adrenal cortex occurs during prolonged stress exposure while others concluded that prolonged exposure to acute stress results in a decline in adrenal sensitivity (McNutty and Thurley 1973, Ader 1975).

Alternatively, Sapolsky (1983) suggested that chronic stress might cause a decline in cortisol production as a result of impairment of pituitary ACTH production, while others (Friend et al. 1977, 1979, Paul et al.

1971, Barrett and Stockham 1963) provide data, which demonstrates that stress tends to increase adrenal sensitivity to an acute stressor.

If chronic exposure to stressors causes sustained elevated glucocorticosteroid levels, impairment of immuno-defensive mechanisms in affected animals may occur making the animals more susceptible to disease (Jensen and Rasmussen 1970, Paape et al. 1973, Hartman et al. 1976, Stein et al. 1976).

Some animal studies have concentrated on the results of deliberate exposure to disturbance. Harlow et al. (1987) using domestic farm sheep determined that mild, medium, and severe stress events resulted in heart rate and plasma cortisol changes. Heart rate during mild stress events returned to resting values by 10 minutes post-stress event, while medium and severe stress events resulted in elevated heart rates for 20 and 60 minutes post stress event, respectively.

Plasma cortisol levels were significantly elevated above resting values within minutes post-stress, with cortisol levels returning to pre-stress levels 30 minutes after removal of the mild stressor; as compared to continuously elevated cortisol levels from 90 to 180 minutes for both the medium and severe stressors.

During chronic stress events, cortisol levels in the sheep were significantly elevated from day 5 through day 24 at which time the random noise generator used to create the stress event failed. Once the generator was repaired and restarted, cortisol levels increased to previous chronic stress values.

The results of Harlow et al. (1987) do not support the concept of adrenal exhaustion or hypersensitization nor suggest that habituation to stressors occurred, perhaps because of the irregular, unpredictable interval of the noise stimuli.

As indicated by Harlow et al. (1987), chronically elevated blood cortisol may adversely impact the efficiency of animal production by reducing weight gain and otherwise affecting animals in captivity (Van Mourik and Stelmasiak 1984, Van Mourik et al. 1985) and decreasing antibody production, thereby inhibiting or suppressing the body's ability to resist disease (Roth 1984, Jensen and Rasmussen 1970, Huber and Douglas 1971, Revillard 1971, Paape et al.1973, Hartman et al. 1976, Stein et al. 1976).

These impacts, particularly if chronic, can result in: increased sickness, disease, and death; a decrease in animal productivity (Knight and Cole 1991, Anderson and Keith 1980); and ultimately result in population declines (Anderson and Keith 1980).

Harassment of mule deer by all-terrain vehicles, for example, resulted in reduced reproduction the following year (Yarmaloy et al. 1988). Common loons experienced reduced productivity with increased human contacts (Titus and VanDruff 1981).

The previous paragraphs clearly denote that stress is a cause for concern with regard to the effects upon creature behaviour. Noise even when at levels below normal receptive hearing is a cause of distress.

Noise can be perceived as a threat and Ising and Ising studied this reactor in 2002. They found a body releases cortisol even during sleep if noise is deemed threatening. Stress disrupts the normal cortisol pattern. Children were studied after being exposed to changed traffic levels involving exposure to high levels of nighttime lorry noise. Indications were that the LFN content produced concentration problems in the children.

Laboratory studies have also been conducted upon human subjects that confirm enhanced salivary cortisol levels were produced by exposure to low frequency noise (Persson-Waye et al., 2002). A further study (Persson-Waye et al., 2003) found that levels of the cortisol awakening response were depressed after exposure to LFN and was associated with tiredness and negativity through the effects of LFN upon sleep quality.

These experiments upon humans all confirm that stress and disturbance are interrelated. There is no reason to conclude the effects upon wildlife would differ.

A recent investigation and report published by the UK Noise Association[38] into wind farms and noise concluded that the symptoms people 'feel' from LFN emitted by land based wind turbines are very similar to those associated with vibroacoustic disease.

This publication contained a number of examples where human distress was reported apparently resulting from low frequency noise and or infrasound affecting them and their homes. Complaints included headaches, worry, lack of sleep, anxiety, irritation and reports of 'feeling' as much as 'hearing' the noise.

One of the recommendations made by the report is that no wind turbines should be sited closer than one mile away from the nearest dwellings and there may even be occasions where a mile is insufficient.

Bearing in mind that many other creatures may be 'trapped' in habitat within these distances there would also seem to be potential for stress and harm to them as well.

Another study for the Ministry of Defence by Keele University concluded seismic signals from wind turbines registering up to 7.5hz could be detected ten miles from a wind farm. Presumably however the dB level at that distance would be low, but it demonstrates how widespread LFN can become from a known manmade source.

Rural areas are usually much quieter than urban conurbations and the sudden introduction of greater noise levels by building a new arterial road; airport or even a wind farm is bound to have an immediate effect upon the residents of sparsely populated regions.

What is almost invariably forgotten during such eventualities is that the resident population includes the natural inhabitants as well as humans. Whereas the human population tends to endure the noise, albeit under sufferance the wildlife (creatures in still freshwater excepted) is far more likely to be driven away, especially if they experience symptoms similar to those found stressful by their human counterparts.

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[38] Location,Location,Location : John Stewart July 2006

HABITUATION

Although people often believe they get used to night time noise, physiological tests point to the contrary. Studies have shown that while the subjective response improves with time, cardiovascular responses remain unchanged (Muzet, 1983). Vallet et al. (1990) conclude that habituation is not complete, even after 5 years of exposure to noise.

There is no reason to suppose the effect upon other mammals, birds or aquatic species would be any different, especially those with nervous systems similar to man.

Impulsive or other sudden loud sounds can produce a startle response that does not completely habituate with repeated, predictable exposures (May and Rice, 1971).

Knipschild and Oudshoom (1977) avoided some of the pitfalls characteristic of epidemiological studies by examining a population near the Amsterdam airport before and after an increase in exposure to aircraft noise, and comparing it to a non-exposed nearby population.

The dependent variable was the purchase of certain prescription drugs: tranquillisers, sleeping pills, antacids, and cardiovascular drugs. The investigators found that the use of these drugs in the non-noise area was essentially stable, whereas the use of most types of these drugs in the area newly impacted by noise increased steadily over the years investigated. This increase was especially noticeable for anti-hypertensive drugs.

The evidence is fairly clear that so long as the stimulus remains the same, noise annoyance does not subside over time (e.g., Fields, 1990). Griffiths (1983) cites studies showing no habituation for highway noise from four months to two years after the opening of new routes. De long (1990) found that annoyance in a previously surveyed community increased by 10 percent with no change in noise levels. He suggests that this increase could represent a shift of internal criteria due to increased publicity and other factors, or perhaps an increase in physiological sensitisation.

Annoyance is not peculiar to human beings, it is just easier to grasp as a human concept as the type or degree can be communicated in ways we more readily understand. Unfortunately we cannot simply ask for example, a frog, if the noise from water pumps gets on its nerves. We have to rely upon behavioural study and assume if the frog leaves the vicinity it might have been due to the noise emitted by the pumps and then eradicate all other known causes and possibilities.

It has already been noted elsewhere in this literary report that bees did not habituate to noise and actually ceased movement for an appreciable time after exposure. Conversely comment has also been made that mink appeared to become used to acoustic stimuli and vibration and the bird-scaring device that emits a regular sound is not as effective as the intermittent unpredictable noise.

Accordingly it appears the type of noise, frequency (in terms of period scale or regularity as well as the actual Hz level), unexpectedness and 'loudness' may play a part in habituation as much as the nature of the species themselves. Yet such apparent habituation may simply be that certain species are more tolerant than others to certain levels of disturbance.

Starlings for example have been observed reacting to the explosive sound of a bird-scaring machine[39] by flying en masse from a temporary roost and then returning to settle again in the same area after a few minutes. Possibly the urge to feed overwhelms the 'fright' once it is interpreted as temporary and no other obvious source of danger arises.

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[39] Noted by the author on various occasions during 2005 and 2006.

The 'silent' noise of infrasound and LFN at the lowest end of the spectrum being emitted continuously would appear to be more troublesome than an occasional loud retort. Inaudibility other than in a tactile sense could create long-term distress if the affected creatures could not escape exposure and habituation would be unlikely to occur.

Audible low frequency traffic noise can produce a partial habituation and has been mentioned as leading to possible familiarity causing danger indirectly, such as a creature being 'used' to the sound and taking a risk to cross a road.

Birds and other wild creatures can be tamed with the repeated provision of a food supply. They would still be startled by intervention of an unexpected noise but also seem to overcome fear of some types of noise as evidenced by flocks of gulls following a tractor and plough. This is not true habituation but is more likely a calculated assessment of the situation where the abundance of food is balanced against the likely-hood of intervening danger.

On the other hand familiarity and tolerance sometimes appear to grow in tandem. Rabbits whilst extremely nervous of any unexpected movement will quite happily feed alongside of a noisy and busy road provided there is sufficient distance between them and the regular passing traffic. Youngsters to their cost often have complete disregard for the danger and seem oblivious to the traffic sounds.

Habituation is therefore possible in certain circumstances but might still result in creature damage or distress occurring. There would also appear to be degrees of habituation or tolerance, which may or may not be harmful.

In general it seems that habituation cannot be relied upon as a creature safeguard against the emission of either continuous or spasmodic LFN and infrasound.

See Appendix B for a summary of the effects of noise upon creatures.

CONCLUSION AND RECOMMENDATIONS

Behavioural studies of the effects of low frequency noise and infrasound upon wildlife are few and far between. Those that have been conducted seem conclusive in their findings in that all confirm harm is possible to living creatures when exposed to prolonged high intensity noise levels.

Mostly it appears noise is just as stressful to wildlife as to humans whether of low or high frequency but is species dependent with regard to the extent of the effects. Generally, creature response is one of appearing startled if the noise is sudden with increased stress if prolonged. In essence, as might be expected, the effects are similar to human behaviour.

The absence of controlled experiments is understandable for rarely is it possible outside of laboratory conditions to create situations that replicate 'the real thing' and to project the findings from an artificial environment could lead to questionable results.

Naturally occurring wildlife populations are undoubtedly sensitive to environmental noise imposed upon them by manmade features. Indeed the level of sensitivity is largely determined by their response to transient perturbations (Shepherd and Horwood 1979). When the source of noise is spasmodic or infrequent a return to normal might be anticipated and recovery rate maybe comparatively quick.

Whilst this suggests occasional disturbance is seemingly harmless or relatively innocuous it does depend upon the duration between events as well as other factors. Regular pulses of sound that occur between long intervals without disturbance can sometimes lead to habituation, but on other occasions create just as much of a startle factor as the 'one off' event.

Thus at times the startle factor seems to be of little consequence although there are exceptions such as abandonment of habitat or in the case of nesting birds, desertion of eggs or young. More prolonged and intense exposure however, has a worsening effect and in the case of species contained within an enclosed environment, such as pond dwelling creatures the results could be significantly harmful.

Despite an undoubted increase in general noise levels and the growth of manmade inventions producing differing levels of sound, very little progress seems to have been made in terms of actual research into the effects upon wildlife over the past 30 years.

Environmental impact assessments rarely consider noise effects on wildlife. According to Bender in 1977 a complete and accurate assessment of a given impact should include an assessment of how animals will react (both physically and behaviourally) to various noise levels of varying frequencies produced by the impact.

In 1980 Fletcher stated that further research is needed to answer critical questions about the effects of noise on animals, including long and short term noise effects and the effect of noise on declining animal population regardless of the cause of the population decline.

By 1988 Manci et al. still reported a lack of field studies and opined the vital link missing in understanding the effects of noise on wildlife was information concerning observation of behavioural response to the physiological changes brought about by noise exposure.

Despite the opportunities offered by proliferation of wind turbines, both on and off shore during the late 20^{th} C little or nothing of substance has materialised regarding the influence of LFN and infrasound on wildlife behaviour or their habitat except an underlying cause for concern.

Quite clearly further research is required in an endeavour to resolve critical aspects concerning the effects of noise on land based animals and fresh water creatures. These should embrace studies of affected species both as individual creatures and in accumulated groups (e.g., shoals) to examine the acoustic frequency, intensity and temporal patterns of significant sound sources upon mating, habitat, alarm response and nurturing.

In addition investigation of the spectrum of environmental sound upon wildlife hearing sensitivity and effects of noise on declining populations of wild creatures should be undertaken. Attention should also be paid to examining the direct stress effects of noise combined with any other related factors e g., habitat damage on wildlife behaviour covering both long and short-term exposure periods.

Prediction of the consequences of low frequency noise and infrasound upon wildlife is difficult to second guess for in addition to not being broadly species dependent it is also not entirely habitat relative. Some creatures could adapt and some could not. Some habitats attenuate sound others intensify it.

In an ideal world a full safety first approach would be adopted and low frequency noise or infrasound emissions would be prevented from affecting wildlife entirely. Unfortunately the doctrine of impossible perfection cannot be applied. Consequently further studies should be made of existing and known localities 'suffering' exposure to this type of noise.

Representations must be made wherever and whenever possible to those responsible for planning, constructing, building, erecting and utilising equipment that emit low frequency noise and infrasound to adopt a proactive and protective attitude towards wildlife.

The track record is neither admirable nor encouraging despite tightening of wildlife legislation across Europe. Even the sudden shift of high-level emphasis upon combating global environmental change resulting from apparent human climatic influence does not auger well.

Permitting construction of vast numbers of large-scale renewable energy projects that produce virtually continuous emissions of infrasound could have wide-spread, marked adverse consequences for the creatures they are intended to help protect.

More factories will be built to provide the equipment used to harness wind, water and solar power as well as additional nuclear power stations. Old power stations will be rebuilt or demolished. All will give rise to some levels of low frequency noise during the construction process and more large transport vehicles will be required to move equipment and spoil from excavations.

Meanwhile there is unlikely to be a reduction in road, rail and air travel or erection of new housing, schools, shops and offices in areas currently inhabited by wildlife. This means more quarrying, road laying, rail improvements, airports and building activities encompassing green field sites.

The prospects are not good. Infrasound and low frequency noise problems will multiply unless more stringent checks are devised at the manufacturing and operating stages. This can only be done by stricter legislative controls on noise emissions and more sensitive placement of any structure that has the capability of emitting these types of sounds.

Measuring methods must therefore be reviewed to include 'C' Weighting and 'G' Weighting at all stages of planned development where LFN and infrasound emissions are anticipated.

Planning authorities should be properly equipped with the means, personnel and equipment to undertake noise investigation and monitoring for at present it appears in many instances they are not able to embark upon even the most rudimentary testing.

An independent environmental assessment is essential to include infrasound and low frequency noise tests at source with prediction models showing the anticipated noise levels at progressive distances and showing the predicted spread.

The assessment must also make a complete study of all wildlife in and immediately beyond the projected vicinity with a proper chronicle of species over a realistic period commencing with an intensive base line study of one year of full and representative observation before a planning application is submitted.

Current wildlife bodies such as the various charities and trusts concerned for wildlife and habitats could carry much of this work out if appropriate government funding was diverted and controlled for the purpose.

Thereafter regular, periodic seasonal monitoring should be enforced as part of the planning acceptance, conditional upon immediate cessation of noise emission if found detrimental to any affected species.

Unless the problem is recognised as real and acute the potential for further chronic and significant harm to land based animals and fresh water creatures will multiply and almost certainly contribute to the progressive decline in species and habitat.

APPENDIX A

i) "Selected Health risks caused by long term, whole body vibration" by Seidel H. Federal Inst. Of Occupational Health, Berlin. (Am J. Med. 1993 Apr. 23(4) ; 589 – 604.)

ii) "Characterising the effects of airborne vibration on human body vibration response" by Smith S.D. Air Force Research Lab., Wright – Patterson AFB, USA. (Aviation. Space Environment. Med. 2002 Jan; 73 (1); 36 – 45

iii) "Low frequency noise enhances cortisol among noise sensitive subjects during work performance" by Kerstin person-Waye. J Bengtsson, R. Rylander, F. Hucklebridge. P. Evans, A. Clow. (Dept. Environ. Medicine, Univ. of Gothenburg. (Life Science 2002 Jan 4; 70(7) 745 – 58. .

[See also by same team "Effects of night time LFN on the cortisol response to awakening and subjective sleep quality)

iv) "Noise induced Endocrine Effects & Cardiovasccular Risks" by H. Ising, W Babisch, B. Kruppa, Federal Environ. Agency, Inst. Of Water, Soil & Air Hygiene, Berlin.(Noise Health 1999; 1 (4); 37 – 48.

v) "Coping with stress; Neuroendocrine Reactions & Implications for Health" by U. Lundberg, Dept. of Psycchology, Stockholm. (Noise Health 1999; 1 (4); 67 – 74

vi) "Possible health effects of noise induced cortisol increase" by M. Spreng. Dept. Physiology, Univ. Erlangen, Germany (Noise Health 2000; 2(7); 59 – 64

vii) "Acute and chronic endocrine effects of noise": Review of the research conducted at the Inst. For Water, Soil & Air Hygiene, Berlin. H. Ising, C. Braun (Noise Health 2000;2(7) 7 – 24.

APPENDIX B

Creatures and the effects of noise exposure

Species	Effects
Alligators	Use infrasound for communication
Amphibians	Displacement by traffic noise
Badgers	Avoid traffic at noisiest periods
Bees – Honey	Ceased moving up to 20 minutes and didn't habituate
Bird – Black Tailed Godwit	Traffic noise reduced density and breeding numbers
Bird – House Sparrow	LFN from mobile phone masts – possible contributor to decline
Bird – Lapwing	Traffic noise reduced density and breeding numbers
Bird – Oystercatcher	Traffic noise reduced density and breeding numbers
Bird – Raptors	Disturbed by chain saws
Bird – Raven	Distress and disturbance from sonic booms
Bird – Skylark	Traffic noise reduced density and breeding numbers
Bird – Stone Curlew	Traffic noise, movement caused disturbance
Bird – Waterfowl	Traffic noise reduced density and breeding numbers
Bird – Willow Warbler	Lower density of territorial males due to traffic noise
Birds	17 of 23 species negatively affected by road noise
Birds	Masking effect of LFN exposed to wind turbine rotor blade danger
Birds	Communication (song and calls) masked by LFN
Birds	Silenced by anticipating seismic signal preceding sonic boom
Cattle – Dairy	Reduced haemoglobin and increased glucose in blood by LFN exposure from tractor
Chinchilla	Auditory damage
Cod	Affected by Wind Turbine Noise at 120dB at 16Hz
Cow	Fright noise led to 30 minute cessation of milk production and reduced feed intake
Deer	Displacement by traffic noise
Dog – Poodle	Heard extremely soft infrasound tone (-4dB)
Dolphins – Bottle Nosed	Possible interference with vocal range
Earthworms	Move towards surface at 5Hz
Elephants	Use infrasound for communication
Elk	Avoidance of road noise
Fish	Negative response and avoided acoustic field
Fish	Use lateral line system to detect acoustic signals at low frequency
Fish – In Tanks	Noise exposure influenced fat stores, growth and reproduction
Fish – Gold	Physiological stress, hearing loss from white noise

Species	Effects
Fish – Marine	Egg viability and fry growth rate reduced
Fish – Pink Snapper	Ear damage by loud LFN
Fish – Salmon	Respond to LFN particle motion
Flies – Diptera	Startle response to LFN
Fox	Avoid traffic at noisiest periods
Fox – Red	Slight reactors to LFN in feeding tests
Frog – Tree	Acoustic avoidance behaviour
Giraffes	Use infrasound for communication
Goats	Reduced milk yield
Guinea Pigs	Vascular, myocardium, conjunctiva, liver, metabolism and auditory changes
Hedgehog	Probable tactile response to LFN under 25Ohz
Hippopotamus	Use infrasound for communication
Insects – Aquatic	Numbers declined with increased traffic volume
Lizard – Mohave Fringe Toed Sand	Dune Buggy noise caused hearing loss
Mayfly	Concern over noise and vibration by wind turbine process on larvae
Mice	Lung damage and adrenal weight differences
Midges – Chironmidae	LFN acted as possible attractor
Moles	Retreat from 90dB+ sound source
Moose	Affected by traffic noise and caused displacement
Okapi	Use infrasound for communication
Pigs	Hormonal disturbance, water and sodium retention
Porpoises – Harbour	React to simulated, wind turbine water borne sound
Poultry	Reduced egg laying
Rat – Kangaroo	Hearing physiology affected by ORV noise
Rats	Vascular, myocardium, conjunctiva, liver, metabolism, auditory changes
Rats	Head and eye movement responses
Rats	Brain – slight impairment
Rhinoceros	Use infrasound for communication
Seals	Pregnancies aborted possibly due to pile driving
Seals - Harbour	Clicks increased by simulated wind turbine noise, surface at larger distance from sound source and leave area when ‘pingers’ operate
Sharks	Attracted by broad band low frequency regularly pulsed sounds (20Hz –100Hz)
Sheep and Lambs	Heart and respiratory rates increased and lowered feeding efficiency.
Shrimp – Brown	Reduction in reproduction and growth rates. Aggressive behaviour (cannibalism)
Snake – Adder	React to vibrations
Snake – Grass	React to vibrations
Squirrels	Avoid traffic at noisiest periods

Species	Effects
Squirrels – Ground	Enforced behavioural changes
Toad – Spadefoot	Confused by motorcycle noise – affects breeding
Weasels – Least	Sensitive to low frequencies
Whales	Avoid areas with sound commencing at 120dB
Whales – Singing Humpback	Disturbance, abandoned habitat including breeding, feeding and calving grounds
Whales – Sperm	Disturbance, abandoned habitat including breeding, feeding and calving grounds

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