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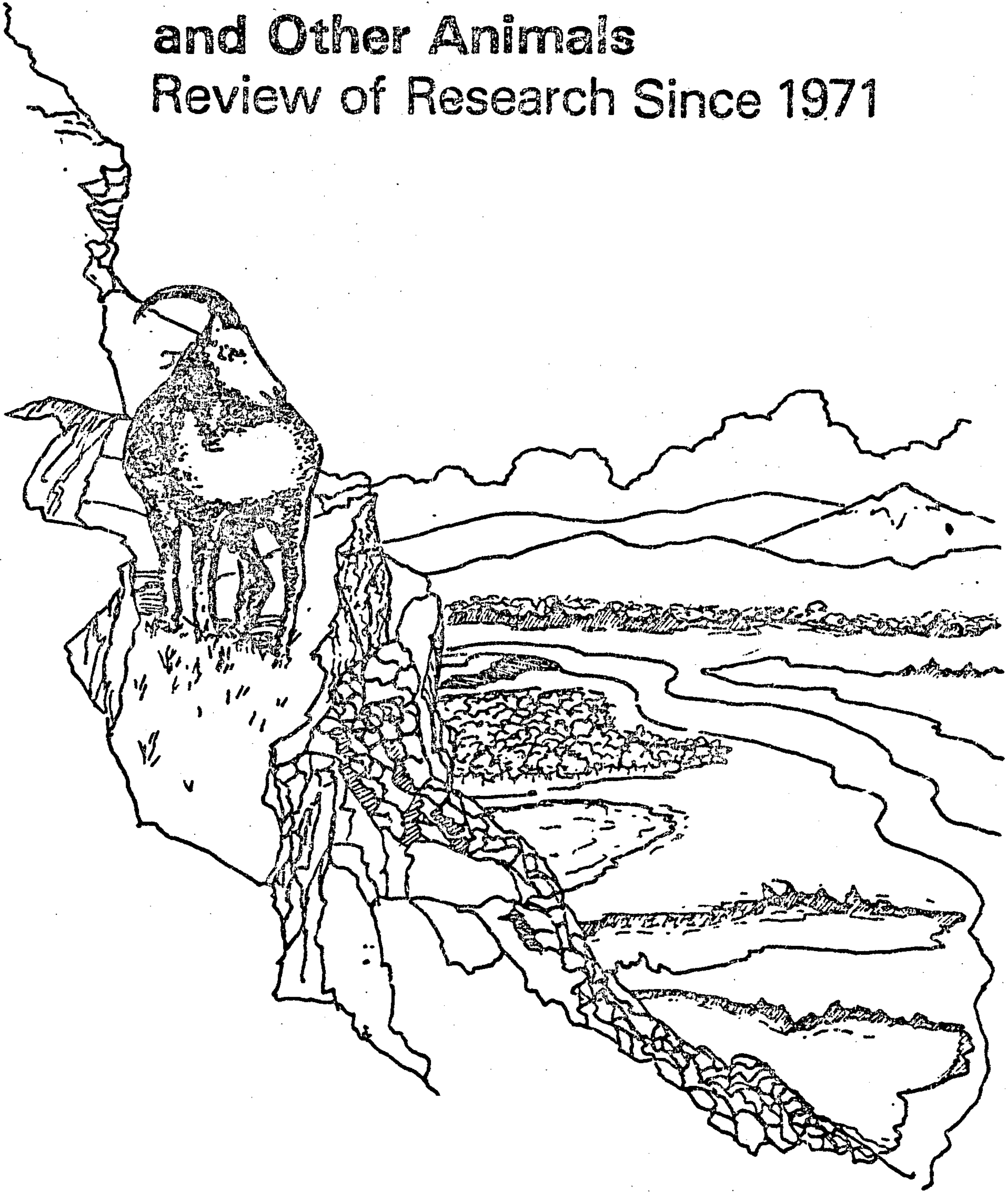
# Effects of Noise on Wildlife and Other Animals

## Review of Research Since 1971



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16\. ABSTRACT

This report represents a survey of the most significant studies since EPA issued its first report concerning noise effects on wildlife in 1971. The report has been divided into three main sections: laboratory animals, domestic animals, domestic animals, and wildlife. Studies within each of the three sections are further arranged by taxonomic groups and/or individual species, depending on the amount of material available. Reports on each species or taxonomic group are presented in four major categories of noise effects: auditory physiological, masking, nonauditory physiological, and behavioral.

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# Effects of Noise on Wildlife and Other Animals

## Review of Research since 1971

# PREFACE

The following report is a survey of research on the effects of noise on wildlife and other animals. It was produced in response to a large number of requests for information on this topic, and to address requirements of the Noise Control Act of 1972, as amended by the Quiet Communities Act of 1978.

No quantitative criteria are proposed in this document, largely because the body of research on any given question is not sufficient to support the establishment of criteria. More research is needed before quantified dose-response relationships can be determined.

Although the report does not attempt to identify levels of noise which will protect animals from adverse noise effects (as has been done for humans), it does provide important information for Federal, State and local officials, researchers, environmental and conservation organizations, and concerned individuals. Among other uses, it is intended to assist in developing Environmental Impact Statements on projects affecting animal environments.

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# INTRODUCTION

## HISTORY, SCOPE AND INTENDED READERSHIP

Human beings have steadily been engulfing many species of wildlife, reducing the space available and damaging the space remaining through environmental pollution. The impact of this encroachment on wildlife includes 1) loss of habitat and territory; 2) loss of food supply; 3) behavioral changes involving mating, predation, migration, and other activities; 4) changes in interspecies relationships, such as altered predatory-prey balance and other aspects of population dynamics, increased competition for food, shelter, and other limited resources necessary for life. The role that environmental noise plays in the impact of humans on wildlife is the focus of this report, although information on domestic and laboratory animals is also presented. For the purposes of this report, domestic animals include livestock, poultry, and other animals raised by humans.

This is the second EPA report on noise and wildlife. The first report was issued in 1971 (Fletcher, 1971). While it was not intended to be an exhaustive search of the world literature, it did reflect the most important data then available. Since then the world literature has grown slowly but significantly. Besides the publication of individual studies, some of the most notable informational events have been the following:

- Symposium on the Effects of Noise on Wildlife, at the 9th International Congress on Acoustics (ICA), Madrid, July 1977. Sponsored by a working group of the Special Committee on Problems of the Environment (SCOPE) of the ICA, this Symposium led to the publication of a collection of topical papers the following year (Fletcher and Busnel, eds., 1978)
- Panel on Effects of Noise on Animals at the Third International Conference on Noise as a Public Health Problem, Freiburg, West Germany, September, 1978. The papers presented have been published in the Conference Proceedings (ASHA, 1980)
- A review written for EPA (Fletcher, unpublished)
- An extensive bibliography on the effects of noise on non-human vertebrates (Bondello and Brattstrom, 1979a)
- A report to be issued in 1980 by a workshop on the interaction between man-made noise and vibration and arctic marine wildlife, sponsored by the Acoustical Society of America.

The intended readership of this report is diverse, and includes government officials, researchers, and concerned citizens and environmental or conservation organizations. Although the information needs of this readership are not identical, it is hoped that the information in this report will be useful to all groups.

## ORGANIZATION OF THIS REPORT

The report has been divided into three main sections: laboratory animals, domestic animals, and wildlife. Studies within each of the three sections are further arranged by taxonomic groups and/or individual species, depending on the amount of material. Reports on each species or taxonomic group are presented by the four major categories of noise effects: auditory, masking, nonauditory, and behavioral effects. In some sections, one or more of these effects categories have been omitted due to lack of information.

Throughout this document, sound levels and exposures are reported in the investigators' terminology. In some cases, the details of reference levels, weighting schemes, and other acoustic parameters were not given in the original sources.

## OVERVIEW OF EFFECTS OF NOISE

### PRIMARY AND SECONDARY EFFECTS

Noise has the potential for affecting organisms in a large number of ways. The effects of noise on animals may be divided into primary and secondary effects. Some hypothetical examples of each are offered for purposes of clarification (See Table 1). It will be noted that primary effects are the direct physical effects experienced by the organism, while secondary effects are reflected in changes in the functioning or performance of the organism vis a vis its environment.

Thus, the major primary effects of noise on animals may be the same, whether animals are in the laboratory, on a farm, or in the wilderness. Secondary effects may be different depending on the life functions of the particular species.

**TABLE 1. Hypothetical Examples of Primary and Secondary Effects**

| Type of Animal | Primary Effects | Secondary Effects |
|---|---|---|
| Birds | Masking of signals | Interference with mating |
| Small animals | Masking of signals | Changes in predator-prey relations, leading to changes in animal populations |
| Agricultural, Domestic | Stress; physiological responses | Changes in meat quality and milk production, weight gain, egg-laying, egg-hatching |

In this report both primary and secondary effects may be addressed, depending on the data available for a species.

## HEARING

The study of the effects of noise on hearing involves both the description of the normal hearing ability of an animal and hearing loss due to noise. These two aspects of hearing have been studied frequently in laboratory animals, but very little in domestic or wild animals. The effects of noise on hearing have thus been discussed in the next section on laboratory animals.

## MASKING

The inability to hear important environmental cues as well as signals from other animals because of the presence of other sounds is called masking. Masking of signals of significance to animals may result in difficulties in finding mates, in escaping predators, and in communicating with other members of their species.

## NONAUDITORY PHYSIOLOGICAL EFFECTS

The nonauditory effects of noise are not well documented in wild animals. A nonauditory physiological effect may involve any physiological parameter other than hearing damage, from hormone levels in the blood or urine to heart rate or respiration. Individual researchers have chosen a wide variety of different physiological effects of noise to measure in animals. What ties all of these physiological parameters together is the body's reaction to stress. The concept of noise as a stressor is basic to understanding the nonauditory physiological effects of noise on animals. A stressor can be any agent that causes stress, including both physical and psychological factors in an organism. Because of the technical terms involved, more information on stress is provided in the Appendix. It includes information on stress in general and on noise as a stressor in particular.

## BEHAVIORAL EFFECTS

Noise can be very frightening and disturbing to both humans and lower animals. Animals vary tremendously in their overt responses to noise, ranging from near indifference to flight. The behavioral reaction of an animal to noise depends on the source of the noise, whether or not the noise is expected, the acoustic characteristics of the noise (loudness, duration, frequency pattern), the experience of the individual animal, and whether or not other stressors are present (e.g., frightening objects, humans, chemical or physical agents).

There are many reports of animal responses to noise from sonic booms, aircraft flyovers, power transmission lines, and many other noise sources. Enough data have been collected to be able to predict the behavior of certain types of animals, including domestic species and wilderness species such as wild sheep, caribou, and moose.

# SECTION I. LABORATORY ANIMALS

## INTRODUCTION

This laboratory research section is included in this report because the findings display the range of potential effects which may occur in other environments under comparable conditions. It should be noted, however, that most of the laboratory research is conducted for the purpose of understanding more about factors affecting humans, rather than to understand these effects on animals in natural environments.

Laboratory animals generally include inbred species raised in special colonies for use in research. Common laboratory animals raised in this manner include many rodents or lagomorphs, such as rats, mice, hamsters, rabbits, guinea pigs, and chinchillas, as well as monkeys and other primates. There are also species commonly used as laboratory animals, which may or may not have been raised under controlled breeding conditions. These species include a number of animals more frequently used as pets, such as cats and dogs. The wild counterparts to any of these laboratory animals will be treated in the section on wildlife.

Although many laboratory animals have wild counterparts (rats, mice), the wild species are clearly different in many ways - genetically, behaviorally, and physiologically. Thus, a major problem with laboratory animal research is the ability to make generalizations about results from one species to another and from laboratory to natural conditions. Despite this constraint, laboratory work offers the advantages of being able to control the experimental conditions, including: (1) the characteristics of the sounds to which the animals are exposed, such as frequency spectrum, duration, pattern of exposure and exposure level; (2) the factors determining species' susceptibility or individual susceptibility to noise induced damage, such as hearing sensitivity and auditory range, age, sex, presence of other stressors, and genetic background.

There are several factors to consider in evaluating the studies presented in this section. The first is that the noise levels used in many of the studies are very high (over 100 decibels). Since these levels are much beyond what we would normally find animals exposed to around airfields, industries, highways, or most other intrusions by man into their habitat, direct generalizations to non-laboratory conditions are inappropriate. Another factor to consider is that the duration of noise exposure is often very short so that most of the studies explore acute rather than chronic effects. A further consideration about these studies is that auditory sensitivities to intensity and frequency vary widely from one species to another. This could be a significant factor, especially with regard to measurement and frequency weighting of noise exposures. In spite of these factors, the studies show that noise can affect many bodily functions and they point out areas for special study in wild and domestic animals.

Due to the very large number of reports available on the effects of noise on laboratory animals, we have selected only a small number of representative original studies and review articles for inclusion in this report.

## HEARING

The study of the effects of noise on hearing includes measuring normal hearing levels for the species being studied and investigating noise-induced hearing loss. The studies in this section will be confined to hearing loss from physiological damage to the auditory system. Another auditory phenomenon, masking, is the result of interference with signal detection by a competing noise, and will be treated separately.

Laboratory animal species differ in both hearing sensitivity and susceptibility to noise-induced hearing loss. Many common laboratory animals, such as chinchillas, cats, guinea pigs, and monkeys, may be more susceptible to noise damage than humans (Peterson, 1980). Rodents, which are the most common laboratory animals, are acutely sensitive to very high frequency sound--up to 60,000 to 80,000 Hertz (Hz, or cycles per second) (Peterson, 1980) and even 100,000 Hz (Lee and Griffith, 1978). Anyone who has had a pet dog or cat knows from observation that these animals are sensitive to higher frequencies than humans can hear (as a dog whistle illustrates). For further information on hearing sensitivities of different animal species, see Busnel (1963).

As in humans, the best documented effect of noise on laboratory animals is the production of hearing loss or damage to the auditory system. This can be produced by a brief exposure to very loud sound or by prolonged exposure to moderate levels of sound. To study hearing loss, it is necessary to measure hearing abilities before and after exposure to noise. Either electrophysiological recordings from the auditory system or behavioral responses of the animal can be used to assess the sensitivity of the ear. The Preyer reflex, and ear-twitch response to sound, indicates that an animal has heard a sound. This reflex is a reliable, but not very sensitive, test of hearing in animals, because they are capable of hearing sounds that are less intense than the sound that produces the response. Alternatively, an animal can be trained to respond to a sound stimulus by using the sound as a cue to obtain reward (such as food) or to escape from punishment (such as electric shock). If the animal is appropriately motivated (i.e., hungry or fearful of shock, depending on the circumstances), its responses can serve as a sensitive indicator of which sounds it hears. An animal's hearing can be tested, the animal then can be exposed to noise, and hearing can be retested to determine the decrease in hearing ability, or threshold shift (Fletcher, 1971).

Brief, moderate noise exposure can result in a temporary threshold shift (TTS), in which there is a temporary elevation of the level of faintest audible sound. Given a sufficient quiet recovery period, hearing will return to normal. More severe noise exposure can result in permanent hearing loss, or permanent threshold shift (PTS). Animal studies tend to confirm findings in humans that TTS grows to an asymptotic level (asymptotic threshold shift or ATS) for a sound exposure of a given level and a relatively long duration (Moody, et al., 1978; Mills, 1976). The relationship between TTS and PTS is still unknown.

A recent study by Liberman and Bell (1979) compared histological data from the hair cells in cochleas from cats raised under normal or noisy laboratory conditions for up to two years. Noise-induced threshold shifts were correlated with loss or damage to the hair cells. Similar studies using monkeys (genus Macaca) and a baboon (Papio papio) correlated cochlear pathology and hearing loss due to chronic exposure to octave band noise of 117 to 120 decibels sound pressure level (Moody, et al., 1976; Moody, et al., 1978).

Besides the attributes of sound level or intensity, it is useful to describe sound in terms of its frequency spectrum. It has been mentioned that animals of different species have different frequency sensitivities. The frequency content of sound is also important because sounds of different spectra affect the auditory system differently, regardless of species. High frequency pure tones or narrow bands of noise tend to produce changes in localized regions of the inner ear, whereas low frequency tones, and random or broad-band noise tend to produce changes throughout the length of the cochlea (Fletcher, 1971). The recent data of Moody, et al. (1978) show that in monkeys (Macaca) hearing losses due to noise were "usually asymmetrical towards the higher frequencies," suggesting that, for these animals, there may be an area roughly between 2000 and 8000 Hz which is more susceptible to damage from noise.

Noise damage in the laboratory is frequently produced by impulse noise. Impulse noise is sound that rises very rapidly to its maximum intensity, such as the firing of a rifle. Because of the very short durations of impulse sounds, they are described in terms of rise time, maximum intensity (peak pressure level), and duration. The rise time of an impulse sound is often around a few thousandths of a second. If an impulse sound is sufficiently intense, the rapid pressure changes produced can cause permanent loss of hearing, usually by destroying sensory cells in the inner ear.

Auditory damage from simulated sonic booms has been found in mice by Reinis (1976). Bleeding in the scala tympani at the basal turn of the cochlea was found after a "super boom" of 10 pounds per square foot overpressure with a 5 millisecond rise time. (This is a much greater sonic boom than humans typically experience in the environment.) The same damage was produced by a less intense sonic boom of 3.3 pounds per square foot overpressure (about 150 decibels instantaneous peak) with a 0.1 millisecond rise time and a duration of 120 milliseconds. When the mice were subjected to repeated sonic booms, an increase in the number of blood clots in the inner ear was observed, even from noise exposure of one boom per day. Bleeding was no longer present after 8 weeks in quiet.

A study by Henderson, et al. (1979) subjected 6 monaural chinchillas to simulated work-week exposure to repetitive, reverberant impulse noise for 5 days, 8 hours per day. The impulse noise consisted of automated brass hammers hitting a steel plate at a rate of one per second. The average peak overpressure was 113 decibels with a reverberation time of 160 milliseconds. Auditory thresholds were measured before and after each exposure, daily for 5 days after the last exposure, and again at 30 days. Thresholds were measured at 250 to 8000 Hz. The noise exposure was found to produce an asymptotic threshold shift. In this study, the higher frequencies (4000 to 8000 Hz) were affected to a greater degree (40 decibel shift) but recovered more rapidly than the lower frequencies (500 to 1000 Hz), which showed a 35 decibel shift. No cumulative effect was observed from day to day, and very little permanent threshold shift was found at the end of the experiment.

Although noise-induced hearing damage has been studied a great deal in laboratory animals, "the complex relations between noise spectrum, noise intensity, exposure duration, and hearing loss are not yet completely understood" (Saunders and Bock, 1978, p. 259). In addition, although many studies have been done on the anatomy, physiology, and biochemistry of noise damage to the inner ear, the actual mechanisms for the noise damage have not been conclusively shown. A detailed discussion of these proposed mechanisms is given by Bohne (1976).

In summary, auditory damage in laboratory animals has been studied intensively for many years. Laboratory animals often serve as models for noise-induced hearing loss mechanisms in humans. There is additional interest in the safety of the laboratory animals themselves, since their condition affects the results of any experiments for which they are used. It is important to note that there are no quantitative exposure limits for animal housing facilities, since damage risk criteria have almost exclusively been investigated for human health. Research is also limited on the existing noise levels of the animal housing areas. The extrapolation of exposure criteria from humans to laboratory animals is extremely questionable (Peterson, 1980).

## NONAUDITORY PHYSIOLOGICAL EFFECTS

Noise may be thought of as a stressor, producing physiological changes similar to those induced by extreme heat, cold, pain, or emotional distress. A major problem is studying the nonauditory effects of noise is to separate the effects of noise from those of other stressors in the environment. This problem exists even in a laboratory setting, where other stressors may include crowding, fear, excess light, toxic substances (pesticides, disinfectant), and various diseases (Peterson, 1980).

The general pattern of response to stress includes neural and endocrine activation, stimulating many changes, such as increases in blood pressure, available glucose, corticosteriod levels in the blood, changes in the adrenal glands and changes in digestive and respiratory activity. These responses are mediated by the sympathetic nervous system (Moller, 1978), which is the part of the nervous system that responds to stress. The sympathetic nervous system and the parasympathetic nervous system work antagonistically to make up the autonomic (or vegetative) nervous system. The autonomic nervous system maintains homeostasis in the body by regulating the composition of body fluids. The autonomic nerves affect circulatory, respiratory, excretory and endocrine functions (Cantrell, 1979), by stimulation of smooth muscle, cardiac muscle, and various glands (such as the adrenals).

A sudden or unfamiliar sound is thought to act as an alarm or warning signal, this activating the sympathetic nervous system. The short-term physiological alarm or stress reactions are similar across many vertebrate species (Moller, 1978). They are often referred to as "fight-or-flight" reactions because they prepare the body to defend itself. The effects of repeated activations of this mechanism in a noisy environment are not understood, but some of the studies discussed in this section address this question.

Some studies show that animals may become accustomed to continuous noise, such that certain physiological reactions to the noise no longer occur (habituation). Habituation to intermittent noise, however, occurs more slowly. For example, this was demonstrated with respect to peripheral vasoconstriction in rats by Borg (1979). There is some evidence that other responses, such as changes in blood pressure, do not seem to habituate, but rather increase in magnitude with long-term exposure to complex noise stimuli (Peterson, 1979; Peterson, et al; 1980).

It is interesting that at the other extreme, the absence of noise can produce a form of sensory deprivation stress, resulting in hypertension and various endocrine changes in rats (Metz, 1978).

An animal's body can respond physiologically to sound stimulation even while the animal is asleep, under anesthesia, or after removal of its cerebral hemispheres (Welch, 1970).

The studies included in this section are presented below according to the various types of physiological effects being explored. Further detailed information on the mechanism of these responses is presented in the Appendix, "Noise as a Stressor."

## CARDIOVASCULAR EFFECTS

The effects of noise on the cardiovascular system, which includes the heart and blood vessels, are among the most frequently demonstrated nonauditory effects. Specific cardiovascular responses that occur include pheripheral vasconstriction, heart rate deceleration, heart rate acceleration, increased blood pressure, elevated serum lipids (free fatty acids, triglycerides, and cholesterol) and increased platelet adhesiveness and aggregation. The animal species most commonly used for studying the cardiovascular effects of noise are rats, rabbits, and more recently, monkeys. A major reason for studying the cardiovascular effects of noise is to see whether chronic noise exposure is a factor in the development of hypertension, atherosclerosis, or other cardiovascular diseases. Although there is evidence that noise is implicated, the results of many studies are conflicting. A comprehensive review of noise, stress, cardiovascular disease, and their interrelationships has recently been completed by Hattis and Richardson (1980). Some of the most significant findings will be discussed here.

Noise stress has been shown to increase plasma renin activity. Since plasma renin activity may be related to hypertension, the effects of noise stress on this measure were studied in rats by Vander, et al. (1977). The noise exposure consisted of broadband noise or a 2000 Hz sound presented at various levels between 80 and 115 decibels sound pressure level for 30 minutes. Control animals on both diets received no acoustic stimulation. Groups of rats given a normal diet were compared to rats given a sodium-free diet, since increased renin activity stimulates sodium retention. No increase in renin activity was produced by the 2000 Hz sound in any of the animals, at any of the levels. Broadband noise significantly increased plasma renin activity in rats on the normal diet but only at the 115 decibel level. The rats on a sodium-free diet showed a significant increase in renin activity when exposed to the 100 decibel broadband noise. Since sodium deprivation increased the effect on renin activity and reduced the noise exposure threshold for the effect, it follows that sodium deprivation may increase the renin-releasing effects of noise exposure and perhaps other stressors.

The development of atherosclerosis due to chronic noise exposure was studied in several groups of female rabbits by Deryagina, et al. (1976). The test rabbits were given either noise alone or noise plus daily oral doses of cholesterol (500 milligrams cholesterol in 5 milliliters of sunflower oil). The noise exposure was 94 to 96 decibels at 3000 Hz for 4.5 hours daily, including two 30-minute quiet periods every 1.5 hours. The total length of exposure was 14 or 28 days. The animals receiving cholesterol were given daily doses for 4.5 to 5 months. Those receiving both noise and cholesterol were given the noise exposure in the first 14 or 28 days. Control groups were given either no cholesterol and no noise or cholesterol alone. Major changes due to noise exposure alone for 14 days included higher blood levels of nonesterified fatty acids and increased blood hypercoagulation. Noise alone induced some microscopic atherosclerotic changes, and noise also enhanced gross atherosclerotic changes in the coronary arteries (such as increased platelet adhesiveness) caused by the high cholesterol diets.

The effect of long term noise exposures on blood pressure and heart rate has been under investigation for the past several years in Rhesus monkeys. Preliminary experiments (Peterson, et al., 1975) showed that both continuous noise (recorded urban noise at an equivalent noise level, $L_{eq}$, of 78 A-weighted decibels) and intermittent noise (signaled noise bursts at 112 decibels for 9 seconds) produced sustained cardiovascular changes. The continuous noise recording was played 12 hours daily for 30 days, after the monkey had been monitored for a 30 day baseline control period. Hourly blood pressure and heart rate measurements were performed. Major increases in these functions occurred in the early morning and declined during the rest of each day. Intermittent noise presented up to 8 times daily for 30 days produced increased heart rate and blood pressure. The most important finding was an overall average baseline blood pressure increase of 28 percent.

This preliminary work was followed up by exposure of Rhesus monkeys to nine months of a daily round-the-clock tape recording designed to simulate the noise exposure of an industrial worker (Peterson, 1979; Peterson, et al., 1980). The tape included an eight-hour period (with a short "lunch break" at noon) of impulsive and continuous industrial noise, transportation noise before and after the "workday" period, household noise in the morning and evening, and low-level sounds such as aircraft overflight noise during the night. The overall equivalent level ($L_{eq(24)}$) was 85 decibels. Monkeys were adolescent females with initial blood pressure levels at about the 50th percentile for Rhesus monkeys. They wore chronically implanted catheters to accurately measure blood pressure levels.

After nine months, the monkeys displayed elevated systolic blood pressure, 137 mm Hg, compared to a pre-exposure average of 106 mm Hg, to an increase of 29 percent. A similar increment was found in diastolic blood pressure.

The noise exposure was then terminated for one month. At the end of this month, blood pressures showed no indication of returning to normal.

Long-term noise exposure has also been studied in the rat (Borg and Moller, 1978), producing very different results from the previous monkey experiments. Both normotensive Sprague-Dawley and spontaneously hypertensive Wistar (Okamoto strain) rats were tested. Groups of rats were exposed 10 hours daily to 85 or 105 decibels sound pressure level over their lifetime of about one year. The noise stimulus was considered meaningless to the rat and consisted of intermittent noise from four Lancing L 75 horns (presented during the night, the time when rats are most active). Control rats were exposed to background noise, produced by the rats themselves, of about 50 A-weighted decibels. No significant long-term differences in systolic blood pressure were found between noise-exposed and unexposed rats in either males or females, or between normotensive and spontaneously hypertensive rats. These results tend to contradict previous findings in rats (Buckley and Smookler, 1970; Geber, 1970).

## NEUROENDOCRINE EFFECTS

For a detailed explanation of some neuroendocrine relationships, see the Appendix. Noise stress may produce many of its effects via corticohypothalamic interactions with the hypophyseal adrenal system. Werner (1959) studied the effect of sound on the hypophysis (the pituitary gland) of the rat. He found that long, continuous bell ringing (8 hours per day) from 1 day to 3 weeks resulted in hypertrophy in the pars intermedia of the pituitary and hyperactivity in the adrenal cortex (increased cortisol secretion).

Ogle and Lockett (1965) studied the effect in rats of recorded thunderclaps of 3 to 4-second duration with a frequency range of 50 to 200 Hz at 98 to 100 decibel sound pressure level, presented at a rate of two claps at 1-minute intervals every 5 minutes for 20 minutes. They compared this effect with that from a pure tone of 150 Hz at 100 decibels presented for 2 minutes out of every 15 minutes for 45 minutes. Urine was collected and analyzed for sodium and potassium. Responses to noise were analyzed through comparisons among animals that were intact, that had denervated kidneys, and that had neurohypophyseal lesions. The authors concluded that thunderclaps produced emotional responses which the 150-Hz tone did not produce. Thunderclaps affected the hypothalamus resulting in excretion of oxytocin (stimulates the uterus) and vasopressin (antidiuretic hormone, which raises blood pressure). These hormones produced increases in sodium and potassium excretion with no increase in urine flow (Fletcher, 1971).

Because the adrenal hormone cortisol is always released during stress, many investigators have measured the effects of noise on adrenal size, cortisol levels in the blood, or the effects of the absence of the adrenals. Yeakel et al. (1948) exposed adrenalectomized Norway rats to the sound of a blast of compressed air 5 minutes a day, 5 days a week, for a year. The average systolic pressure in the noise exposed rats rose from an initial value of 113 mm Hg to 154 mm Hg in the last 2 months, while control values rose from 124 to 127 mm Hg. The absence of the adrenals leaves an animal with no ability to cope with stress by means of increased cortisol secretion.

More recently, Osintseva, et al. (1969) exposed rats to an 80 decibel noise for various times from 18 to 126 days. Following exposure to noise, analyses revealed significant drops in the ascorbic acid contents and weights of the adrenals of these rats relative to the controls.

In another study the same year (Hiroshige, et al. 1969), rats were exposed to continuous bell-ringing for 2 minutes (spectrum and noise level were not reported). Bell-ringing produced an increase in the activity of corticotropin-releasing factor (CRF) in the hypothalamus. This releasing factor (also called ACTHRF) produces the release of adrenocorticotrophic hormone (ACTH) from the pituitary; ACTH, in turn, produces the release of corticosteroids (cortisol, corticosterone, aldosterone) from the adrenals.

Adrenocortical activation has also been studied quite extensively in rodents by Anthony and Ackerman (1955, 1957) and by Anthony, et al. (1959). They exposed rats, mice, and guinea pigs to relatively broad bands of intense noise: 150 to 430 Hz at 140 decibels sound pressure level, 10,000 to 20,000 Hz at 110 decibels, or 2,000 to 40,000 Hz at 132 decibels. Durations of stimulation periods included a single 6 minute exposure, 15 or 45 minutes per day for up to 12 weeks, and cycles of 100 minutes on and 100 minutes off throughout a 4-week exposure period. Although they obtained indications of adrenal activation (as measured by cellular changes in the adrenal glands and a decrease in the number of circulating eosinophils), these changes were generally slight and transient. They did find, however, that intense noise superimposed on another stressor, such as restriction of food, could decrease an animal's life span. The authors concluded that rats, mice, and guinea pigs can become accustomed to noise, but that noise can have damaging effects if it occurs in conjunction with additional stressful situations. They also noted that intense high frequency noise (132 decibels, 2000 to 40,000 Hz) appears to be more stressful than low frequency noise as evidenced by an increase in noise-induced seizures in mouse strains considered to be seizure-resistant (Anthony and Ackerman, 1957).

In the 1970's, noise researchers began using monkeys in studies on cortisol levels. Nealis and Bowman (unpublished) studied the effects of three types of noise on plasma cortisol levels in 12 Rhesus monkeys. The results were compared to those of a control group of four monkeys. The three types of noise consisted of continuous noise (recorded power tools and land vehicles), noise of variable level (rock music), and impulse noise (shotgun blasts, pistol shots, and machine gun blasts, randomly presented). Over a period of 36 days, each of the four test animals was subjected to the three types of noise in exposure sessions of one, three and five hours. A minimum of 90 hours separated the treatments. The average A-weighted noise exposure level was 100 decibels. Test monkeys were divided into 3 groups of two males and two females each. The order of the treatments was randomly assigned for each group. The plasma cortisol levels were not affected differently by the three types of noise stimuli. Elevated plasma cortisol levels were found after one hour of exposure to all three types of noise, but not after the three or five hour exposures. After an initial stress or fear reaction, the monkeys apparently habituated physiologically to the noise.

A similar experiment was performed by Hanson, et al. (1976), except that some of the test animals were able to terminate the noise by depressing a lever (control over noise group). The noise exposure consisted of four 13-minute noise sessions with two minutes of quiet between them. The noise consisted of a continuous recording of power tools, pneumatic drills, snowmobiles, and machinery at 100 decibels. In the first part of the experiment, the 24 monkeys (one- and three-year olds) of both sexes were divided into a control group (no noise), a test group with no control over noise, and a test group with control over noise. The latter group experienced its first 13-minute session with noise before being able to turn it off. In the second part of the experiment, the animals which had had control over the noise in the first part were intermittently presented with the termination lever, but pressing the lever did not terminate the noise. Pre-exposure plasma cortisol levels were equivalent for all three groups. Plasma cortisol levels were significantly elevated both in the group that had no control over noise and in the animals that lost control over noise in the second part. The cortisol levels of monkeys with control over noise were not significantly different from those that had no noise exposure.

Because increased adrenocortical hormones due to stress have been related to decreased thyroid functions, Fell, et al. (1976) studied the effects of acoustic stress on the thyroid glands of rats. The test animals were subjected to a single 1000 Hz tone (at 95 decibels) for 15 minutes, twice per hour for 8 hours daily during the daytime for 12 weeks. The test animals were free of gross hearing abnormalities; based on random inspections during the exposure period. Thyroid activity, measured by uptake of radioactive iodine (I-131), was suppressed in the rats exposed to noise. The suppression began in the first two weeks for females and between two and 12 weeks in the males. Similar sex differences were observed regarding the weight gains of the animals. The females had significantly reduced weight gains during the first 2 weeks of noise stress, whereas the males did not show reductions in weight gain until the sixth week.. A possible explanation for this finding is that altered thyroid function due to stress may decrease the secretion of growth hormone from the anterior pituitary (adenohypophysis).

Another nervous system parameter, activity of acetylcholine (a neural transmitter), was studied in the rat brain by Brzezinska (1968). Exposure to noise (type and level not reported) for 2 hours a day for 3, 6, 9, 12, or 15 days produced a gradual increase in acetylcholinesterase activity (which causes the breakdown of acetylcholine) and an initial increase in acetylcholine concentration followed by a decrease, with a slow return to normal levels by 15 exposures. Since stress induces increased sympathetic nervous system activity, such increases in acetylcholine levels would be expected.

## BIOCHEMICAL PARAMETERS

A number of other effects of noise, particularly on blood chemistry, are included here. Most of the blood levels of various chemicals are related to cardiovascular, neuroendocrine, or a variety of other metabolic functions.

Treptow (1966) found that dogs had transitory increases in glycemic (sugar) levels in the blood prior to becoming used to the stress of experimenter handling. A predictable increase in glycemic reactions was observed in trials one and eight out of 20 exposures to 80 to 87 decibels noise for 5 to 10 minutes each. Due to individual reactions, the measures were highly variable, but by trial 20 the glycemic response had apparently habituated to the noise stimulus.

Stress induces a number of other biochemical changes. Jurtshuk, et al. (1959) subjected two group of female rats to 1 minute of noise daily for 11 days or to 5 minutes of noise for 15 days respectively. The noise consisted of 120 Hz at 100 (± 5) decibels. Rats that displayed the greatest locomotor response upon cessation of auditory stimulation also had the lowest blood glutathione (a respiratory carrier of oxygen). Stimulated rats had higher adrenal weights and ascorbic acid values and lower blood glutathione levels than did their controls.

Geber, et al. (1966) investigated the physiologic response of rats to three durations of acoustic stress (15 to 270 minutes, 19 to 96 hours, and 21 days). The stimulus was a 20,000 to 25,000 Hz sound, ranging from 73 to 93 decibel sound pressure level, presented 6 minutes of every hour. They noted lower eosinophil counts, raised serum cholesterol levels and increased ascorbic acid levels in the brain. Elbowicz-Wariewska (1962) observed that when guinea pigs were exposed for one month to daily 45 minute periods of noise at 160 (± 5) decibels sound pressure level with frequencies from 100 to 50,000 Hz, increases in lactic acid dehydrogenase (LDH) activity and pyruvic acid levels in the blood were observed. Diseased cells tend to discharge greater amounts of certain enzymes into the blood. Elevated LDH is symptomatic of cardiac, liver, kidney, muscle, and brain disorders (Holvey, 1972).

Hrubes (1964) found that nonesterified fatty acids, the plasma lipids most implicated in active transport within cells, increased significantly in female white rats when the rats were exposed to a 95 decibel transmitter generator noise for 16 hours. Hrubes and Benes (1965) demonstrated that white rats subjected repeatedly to 95 decibel noise secreted increased levels of urinary catecholamines, showed increased free fatty acids in blood plasma, increased adrenal size, and decreases in body weight.

Similar findings were reported by Friedman, et al. (1967), who demonstrated that auditory stimulation can affect lipid metabolism. White noise at a sound pressure level of 102 decibels was presented 24 hours a day, and an additional intermittent 200 Hz square wave with a duration of 1 second and a sound pressure level of 114 decibels was programmed to occur randomly with an average interval of 3 minutes. Thirty rats were exposed to the noise stimuli for 3 weeks, and 24 rabbits were exposed for 10 weeks. These animals received standard diets and water, but were administered additional oils to test their abilities to handle excess fat while exposed to noise stress. Plasma triglycerides were higher in noise-exposed rats only during the second week; there were no differences between experimental and control groups of rats at the end of weeks 1 and 3. In the rabbits, however, plasma cholesterol and fasting plasma triglycerides were higher after four weeks of auditory stimulation. Additional differences between the noise-stressed rabbits and the controls included deposits of fat in the irises of the eyes, more aortic atherosclerosis, and a higher cholesterol content in the aortas. The authors concluded that auditory stress produces changes in the metabolism of exogenously delivered fat, having effects similar to those produced by chronic hypothalamic stimulation (obesity).

## PULMONARY EFFECTS

Ponomar'kov, et al. (1969) reported noise-induced pulmonary hemorrhages in dogs. The animals were exposed to 0.6 to 3.5 second bursts of white noise at 105 to 155 decibels. Two hours after exposure, 3-millimeter diameter hemorrhages were found in the lungs of those animals exposed to noise levels exceeding 125 decibels. Increased noise levels resulted in increased numbers of hemorrhages, but not in increases in the size of each site. Emphysematous changes induced by noise exposure were still detectable at 60 days postexposure, even though hemorrhaged blood had been resorbed.

## RESISTANCE TO DISEASE

As explained in the Appendix on stress, extreme elevation of cortisol levels can reduce both the inflammatory response and antibody production (Vander, et al., 1975). It has also been suggested that mild chronic elevation of cortisol levels could also lead to reduced immunity, although definitive evidence of this has yet been found.

At least one experiment has shown there is a relation between noise exposure and susceptibility to viral infection in strains of mice susceptible to audiogenic seizure (see next section). Jensen and Rasmussen (1970) used an 800 Hz tone with an intensity of 120-123 decibels for 3 hours each day on 6- to 8-week old Swiss Webster BRVS mice. Mice innoculated intranasally with vesicular stomatitis virus (causes eruptions in the mouth) just before exposure to sound were more susceptible to the infection, while mice innoculated after the exposure were more resistant. The sound-stressed mice were also more susceptible to polyoma virus (which produces tumors) and developed more tumors than controls that were not sound-stressed. The progression of Rauscher virus leukemia was suppressed in noise-exposed animals. The inflammatory and interferon (a virus-resistant protein produced by cells) responses were also impaired by sound. Sound-stressed mice also had periods of variable susceptibility to viral challenge within each day. At some of these periods, the sound-stressed mice had similar susceptibilities to the non-stressed controls. This transitory change in susceptibility was found to be independent of adrenal function, indicating that other factors may also be involved in disease resistance.

## AUDIOGENIC SEIZURE SUSCEPTIBILITY

Certain strains of rodents are extremely sensitive to intense sound. These rodents undergo such violent audiogenic seizures, that exposure to noise can result in death. Young rodents may become audiogenic seizure-susceptible if exposed to loud noise during a critical period after birth (priming). Priming is used in laboratory rodents to produce experimental animals for the study of epileptic seizures, as models for severe acoustic trauma, and in the study of auditory development in young animals (Saunders and Bock, 1978).

Monastyrskaya et al. (1969) reported that sound stimulation produced increases in weights of the pituitary and adrenal glands in healthy rats, but not in a strain of sound-sensitive, audiogenic-seizure susceptible rats. The sound-sensitive rats already had enlarged pituitaries and adrenals. The rats were exposed to a 105 decibel sound 10 times, for 1.5 minutes each time, with one exposure every 3 to 4 days.

Reproductive effects of noise have also been studied in audiogenic seizure susceptible animals. There is evidence that sound stimulation may induce lasting changes in exposed animals and their offspring in strains of mice that have been specially bred to be susceptible to audiogenic seizures. Lindzey (1951) studied emotionality and audiogenic seizure susceptibility in mice exposed to noise. The animals were stimulated by the sound from a bell attached to a metal washtub (spectrum and sound pressure level were not specified). He reported increased susceptibility to seizure in certain strains of mice. Thompson and Sontag (1956) described effects of audiogenic seizures in pregnant rats on the maze-learning abilities of their offspring. Each of six male albino rats was bred to one experimental and one control female. Two seizures per day were induced from the fifth through the 18th day of pregnancy in each of the six experimental females. Within 24 hours of birth two male and two female pups were selected from each litter and the rest were removed. Three mothers in the experimental group and three in the control group kept their own pups, while the pups of the other three mothers in each group were switched between groups so that pups from experimental (seizure) mothers were cross-fostered on control mothers and vice versa. At 21 days of age, the pups were removed from the others and housed in individual cages in the animal room. General activity levels were tested at 30 and at 60 days of age. Training in a water maze began at 80 days of age. Although there were no significant differences in body weights, litter sizes, or activity levels, there were significant differences between experimental and control groups in maze learning. Pups born to mothers that had audiogenic seizures during pregnancy made significantly more errors and required significantly more trials than did pups born to controls, even if the control pups were cross-fostered on experimental mothers.

## REPRODUCTIVE EFFECTS

Studies on the reproductive effects of noise have examined the impact on both adults and offspring. In adult animals, this research has addressed genital function, fertility and mating. Studies of the offspring of animals exposed to noise during pregnancy have investigated the following parameters: fetotoxicity, teratology, gestation, litter size, birth weight, and aspects of development.

A few studies of noise effects on male reproduction have been done. Anthony and Harclerode (1959) reported negative results in a study of the effects of noise on the numbers of females impregnated by sexually mature male guinea pigs. Twelve weeks of daily exposure to noise (139 to 144 decibels sound pressure level; frequencies of 300 to 4,800 Hz) for 20 minutes out of each 30 minute period did not affect the reproductive performance of the animals relative to their controls. Some evidence of corticoadrenal activation was found, however, suggesting that tolerance limits were approached. Effects of testicular histology were observed by Zoric (1959). He exposed 38 male mice for 8 hours per day for 1 to 21 days to the sound of an electric bell. The level and spectrum of the sound were not reported. Studies of the testes of sound-exposed mice revealed involution (shrinkage) of the seminal epithelium, partial blockage of first order spermatocytes, formation of teratocytes, and atrophy of the epithelium.

Reproductive studies comparing the effects of noise on males and females have also been undertaken. Zondek and Isachar (1964) examined the effect of acoustic stimulation on genital function in 48 mature rabbits and 3,100 young and mature rats. The animals were housed near an electric bell 25 centimeters in diameter that rang 1 minute out of every 10 minutes, 24 hours per day, for 9 days prior to mating. The peak sound pressure level was 100 decibels, with maximum energy at 4,000 Hz, and another peak of 95 decibels at 10,000 Hz. Auditory stress resulted in enlargement of the ovaries, persistent estrus, follicular hematomas, and other effects in female rats and rabbits. Effects were more pronounced in female rabbits than in female rats and were hardly visible in males of either species. Auditory stress during the copulatory period induced increased fertility, but during gestation such stress interrupted pregnancy (Fletcher, 1971).

Another fertility study contained some contradictory findings. Zondek (1964) reported that in rats, the fertility of both males and females was decreased with noise exposure. The males' ability to fertilize was reduced to 11 percent as compared to 70-80 percent in control males; comparable effects were produced in the female rats. Sexual behavior did not seem to be inhibited (copulation was verified by the presence of a vaginal plug), and there were no changes in the weights of the testes and seminal vesicles, nor any noticeable anatomical changes in the spermatogenic process. In similar fashion, Singh and Rao (1970) studied the effects of auditory stress on rat ovaries. They exposed 74 adult female rats to continuous auditory stimulation by a 2,000 Hz tone at 100-decibels (C-weighted) for up to 150 days. Thirty-one animals developed persistent vaginal estrus after 10 consecutive days of stress. As the stress was continued, more animals were affected.

Noise may also affect the offspring of laboratory animals. Ishii and Yokobori (1960) found that female mice exposed to 90, 100, or 110 phons of white noise for six hours per day from the 11th through the 14th day of pregnancy had more stillborn and more malformed young, and smaller embryos than the unexposed controls.

Teratogenic effects produced by audiogenic stress were also reported by Ward, et al. (1970). A motorcycle horn producing 82 to 85 decibels sound pressure level at 320 to 580 Hz was timed to deliver noise intermittently for 60 to 75 percent of each hour. Female albino mice (Swiss-Webster strain) were placed in the chamber and exposed to the noise for periods of at least five hours at different stages of pregnancy. The most severe effects were obtained with stress 8 hours per day on days 8 to 17 of pregnancy. In these cases, 40 percent of the litters were resorbed and mean fetal weight was 0.44 grams, while mean fetal weight in control litters was 1.45 grams. Although only moderate noise levels were used, there were severe results if stimulation occurred during critical periods. Stress during days 7 to 8 resulted in 100 percent resorption by day 18. Observed teratogenic effects (cranial hematoma, dwarfed hind limbs, and tail defects) were attributed to endocrinologic effects of stress on the mother and/or the fetus. These stress effects resulted in discharge of catecholamines and steroids from the adrenals. Decreased uterine and placental blood flow were considered to be responsible for fetal hypoxia and possibly delayed implantation.

Teratogenic and other reproductive effects were studied by Kimmel, et al. (1976) in offspring of pregnant mice and rats subjected to 100 decibel white noise (20 to 20,000 Hz). The mice were exposed to noise during days 3 to 6, 7 to 10, or 11 to 14 of gestation. The rats were exposed on days 6 to 15. The incidence of resorptions (fetotoxicity) was significantly increased and the pregnant females gained significantly less weight during pregnancy in mice exposed on days 3 to 6 and 11 to 14. Maternal weight gain was also decreased in rats, but no fetotoxicity was observed. The authors stated that the lack of teratogenic effects compared to some previous studies may be due to the predictability of the noise stimulation used. More varied noises may produce greater stress. A second experiment compared the rate of spontaneous malformations in mice in noisy versus quiet living quarters during days 1 to 18 of gestation. The quiet quarters had A-weighted noise levels of 30 to 45 decibels, due to the normal activites of the mice. The noisy quarters had noise levels of 50 to 60 decibels, from routine husbandry activities of animal care personnel. The incidence of malformations was not decreased in the quieter quarters, but maternal weight gain was significantly reduced in quiet. The authors suggested maternal weight gain reduction may have been due to other factors related to the quiet quarters themselves.

Since other stressors are often acting along with noise, M.C. Busnel and Molin (1978) studied the reproductive and fetal effects of noise alone and of noise plus 2 other stressors (vibration and crowding in mice). These studies were continuing at the time of publication, so that the results must be considered preliminary. The investigators also wanted to determine whether the results were due to direct effects on the fetuses or due to the indirect effects of stress reactions of the pregnant mice. This was done using three combinations of hearing and deaf mice: (1) Swiss albino males mated to female of the same strain; all adults and young were normal hearing; (2) male hybrid mice carrying the recessive gene for deafness mated to deaf mutant females; 50 percent of the young were deaf and 50 percent had normal hearing; (3) male deaf mutant mice mated to female hearing hybrid, carrying the deaf gene; 50 percent of the young were deaf and 50 percent hearing. Each of the three groups was then subdivided into three treatment groups--noise stress; noise, crowding, and vibration stress; non-stressed controls. The noise stress consisted of 1 hour of recorded subway noise of about 105 decibels played 4 times daily. Vibration and crowding were produced by placing 20 females in one cage on a shaking device for 2 hours daily. All treatments were begun the day of mating and the experiments were continued until each mother's sixth litter, when the females were sacrificed and the fetuses autopsied.

No significant differences were found between experimental and control animals in the mothers' weights, number of young in the litters, number of young surviving to weaning, or the sex ratios of the offspring. Differences were found in weight gain of the young, time interval between litters, and the number of fetal malformations between test and control groups. The mean weight gain of the litters was 25 to 30 percent lower in the noise alone and the noise, crowding and vibration groups in the first three litters of the hearing mothers. Noise alone did not affect the weight of deaf offspring. The interval between litters was very irregular in all of the stressed groups compared to the unstressed controls. The incidence of miscarriage, resorption (absorption of the embryos into the mother's system), and cranial and spinal malformations were also increased in the stressed groups. Noise alone had a smaller effect than in combination with other stressors (crowding and shaking).

## BEHAVIORAL EFFECTS

Loud and unfamiliar noises can be very frightening to laboratory animals as well as other species. Many of the initial behavioral reactions observed are attempts by the animals to escape. Because caged animals usually have no place to run to, the stress may be compounded due to the unavailability of an appropriate (escape) response. Some of the behavioral effects in the studies which follow include altered reflexes, aggression, refusal of food, cessation of grooming, and impaired learning and physical performance.

In one study, rats exposed for 7 days to sound produced by electric bells (for 45 minutes to 2 hours per day) became untidy and less active, refused to eat, and became aggressive (Monaenkov, 1958). Borisova (1960) stated that white rats exposed to 85 decibel noise displayed weakened conditioned reflexes. Five days of rest were necessary for the reflexes to return to normal.

The effects of noise and crowding on young rats were studied by Groh (1965). Permanent effects on activity, learning, and some physiological parameters were produced by raising 80 albino rats in two different litter sizes and under two different sound levels. The rat pups were divided into litters of either 3 or 13 animals, then randomly assigned to lactating females other than their own mothers. Half the rat pups in each litter size were raised in sound-insulated boxes; the other half were raised in regular wire cages in a noisy (sound level unspecified) animal room. There were 10 male and 10 female pups in each of the four groups. After 21 days under these conditions, the rats were weaned and placed, four animals to a cage, in the common animal room for an additional 21 days. At the end of this period (42 days) measures were made of body weights, spontaneous activity in an open field test, heart rate increases following electric shock, and response latency in a straight runway at the end of 20 trials. Open field measures were repeated at 56 days and body weights at 57 days. After these tests, relative weights of the adrenal gland were measured. Rats in large litters weighed less and had larger adrenal glands, indicating stress effects from crowding. Rats raised in sound-proof boxes learned faster (had lower latencies) in the straight runway than did rats raised in the animal room. Decreased activity in the open field test and increased heart rate responses to the sound were more pronounced in rats raised in large litters in sound-insulated boxes and in those raised in small litters in the animal room, than were those in the other two groups. With the possible exception of the cardiac response, all these morphological and behavioral changes appeared to be stable. Thus, noisy and crowded conditions separately were able to produce behavioral changes.

Behavioral changes due to noise were also found in rabbits. Deryagina et al. (1976) noted that rabbits that were subjected to 94 to 96 decibels of sound (at 3000 Hz) 4.5 hours per day for 14 or 28 days became aggressive, fought frequently, and exhibited fright reactions.

Increased aggression was also found in Rhesus monkeys exposed to a 100 decibel noise in the study of Hanson et al., (1976). These monkeys were first able to control or terminate the noise, after which this ability was taken away from them. Another group of monkeys was exposed to 100 decibel noise with no ability to control their exposure. Following their exposure, the monkeys displayed less social contact when placed with small groups of unexposed monkeys.

Similar results were obtained by Nealis and Bowman (unpublished), in that noise-exposed monkeys had reduced behavioral activity and increased non-social behavior, such as sleep. The noise may have produced fatigue in the animals. These effects were noted after 1 and 5 hours of exposure to 100 decibel continuous noise and after 5 hours of 100 decibel impulse noise.

Swimming performance was investigated in a study by Busnel and Lehmann (1978). They studied the effects of both audible and inaudible (including infrasound) acoustic stimuli in normal hearing and in genetically deaf mice, which were from audiogenic seizure-resistant strains. The acoustic stimuli were produced by sinusoidal frequency and white-noise generators at frequencies of 500 to 1000 Hz and 5 to 50 Hz. In this study, infrasound is defined as acoustic frequencies of 30 Hz or less. The mice were subjected to either noise or quiet for 2 hours, after which their swimming times were tested in a tank of water. The high frequency noise reduced the swimming time of the normal, but not the deaf mice. The low frequency noise and infrasound reduced the swimming times of both hearing and deaf mice, although higher sound pressure levels (106 to 115 decibels) were needed to induce fatigue. Although the labyrinthine organs in the ears of deaf animals can still be affected, the authors inferred that infrasound acts by nonauditory means, including visceral and transcranial pathways.

## SUMMARY

Significant effects of noise on both auditory and nonauditory functions have been found in laboratory animals. Effects are particularly severe when very high noise levels are used. These effects include, but are not limited to, the following:

- bleeding in the ear
- increased cortisol levels
- increased blood pressure
- increased blood sugar
- altered heart rate

- changes in blood lipids
- elevated plasma renin activity
- some adverse reproductive effects
- abnormal behavior (increased aggression, reduced social behavior).

We still do not fully understand the relationships among all these effects. Furthermore, we must exercise caution in generalizing the results of these studies, which are mostly short-term, to other situations in which animals are exposed to noise over longer periods of time.

# SECTION II. DOMESTIC ANIMALS

## INTRODUCTION

Although some studies have been conducted on domestic animals of economic importance, lack of uniformity in the measurement and recording of sound stimuli and animal responses to these stimuli makes it difficult to compare results across studies. The domestic animals in these studies include sheep, swine, cows, horses, mink, chickens, and turkeys. Research on noise effects in domestic animals include studies of hearing, behavioral, and physiological responses to different noise sources including: aircraft flyovers and sonic booms, loud noise produced in a laboratory (white noise, music, pure tones, etc.), species-specific distress calls, exploding paper bags, motorboat noise, and artificial bird peeps. The behavioral responses observed most frequently are fright reactions.

Noise, in combination with other environmental factors, has the potential for producing severe stress in farm animals, which may lead to reduced quality of some products and adverse economic effects. Parker and Bayley (1960) noted that the U.S. Air Force has received complaints from farmers about the adverse effects of jet noise on livestock. The studies which follow have attempted to determine whether noise is a significant stressor in farm animals. No studies on masking were available. Because domestic animals are more dependent on humans for survival than on intra- or interspecies communication (which is essential in the wild), masking is not a critical issue.

## HEARING

Auditory thresholds have not been thoroughly studied in domestic animals. As with laboratory animals, variations in audible ranges in different species have important consequences for the response to noise.

In one of the few studies on hearing in domestic animals, the auditory thresholds of 10 Suffolk ewes were measured in an acoustically insulated room with a background noise of 26 decibels, by Ames and Arehart (1972). The measuring techniques included changes in EEG (electroencephalograph) patterns and behavioral responses (ear pricking, head turning, etc.). The auditory threshold was referenced to absolute sound pressure level. The auditory threshold data for the sheep are presented in Figure 1 and Table 2. The most sensitive frequency in sheep is about 7000 Hz.

Auditory thresholds for cattle have also been reported (Ames, 1974). Figure 2 compares the audiograms from 23 cattle and 10 sheep. Note that these audiograms have the same general shape as those for humans, except that the maximum sensitivities of cattle and sheep are in the higher frequencies.

Bond, et al. (1963) studied the effects of loud noise on the anatomy of the swine ear. Animals exposed to five trials of aircraft noise of 120 to 135 decibels showed no injury to the gross anatomy or the organ of Corti in the ear when compared to a control group exposed to ambient airfield noise levels of 70 decibels.

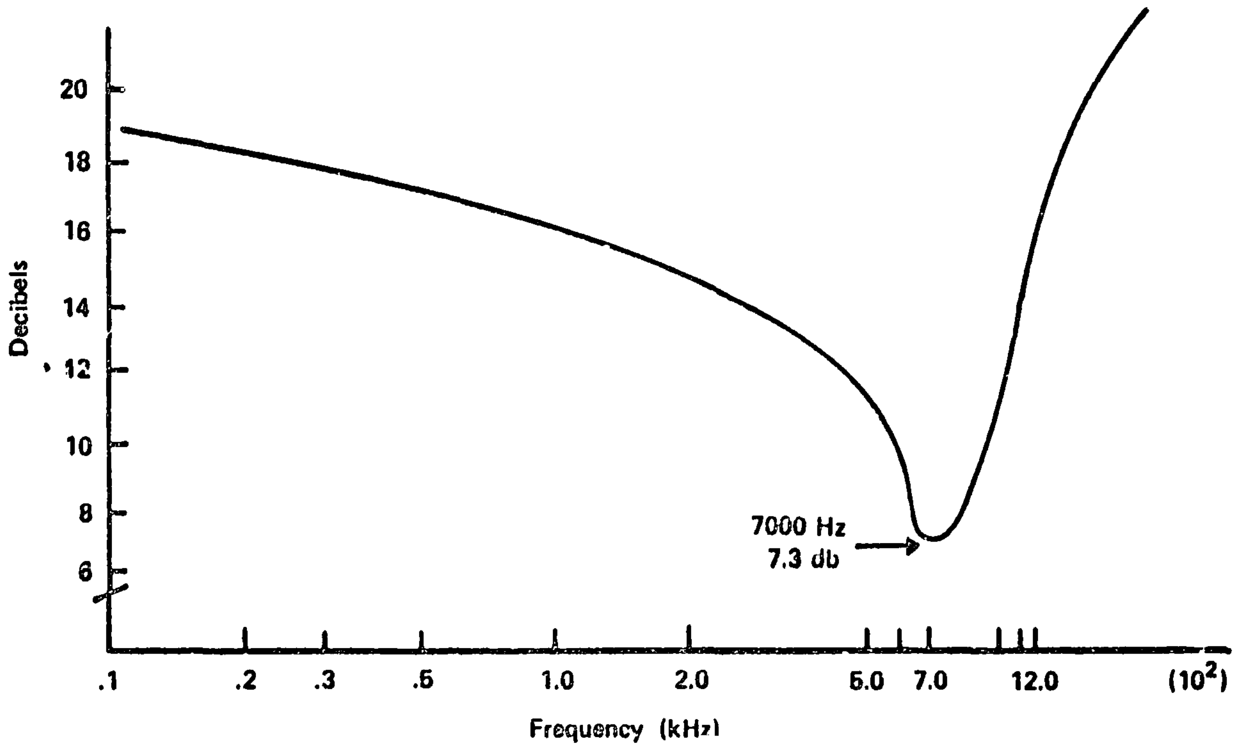

**FIGURE 1.** Auditory Threshold for Sheep. Plot of minimum auditory threshold with decibels shown as sound pressure level above background (28 dB). (Ames and Arehart, 1972)

## TABLE 2

## Mean Auditory Thresholds in Decibels[a, b] (Ames and Arehart, 1972)

| Frequency (Hz) | Decibels (dB) |
|---|---|
| 100 | 18.5±5.0 |
| 200 | 18.1±3.3 |
| 500 | 17.1±2.4 |
| 1,000 | 15.9±4.1 |
| 2,000 | 14.5±2.1 |
| 5,000 | 11.8±0.8 |
| 6,000 | 9.0±0.9 |
| 7,000 | 7.3±0.9 |
| 10,000 | 11.5±0.6 |
| 11,000 | 14.9±1.9 |
| 12,000 | 17.3±1.7 |

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[a] Sound pressure in dB (re 0.0002 dyne/$cm^2$) above background (26 dB).

[b] Each mean represents 30 observations.

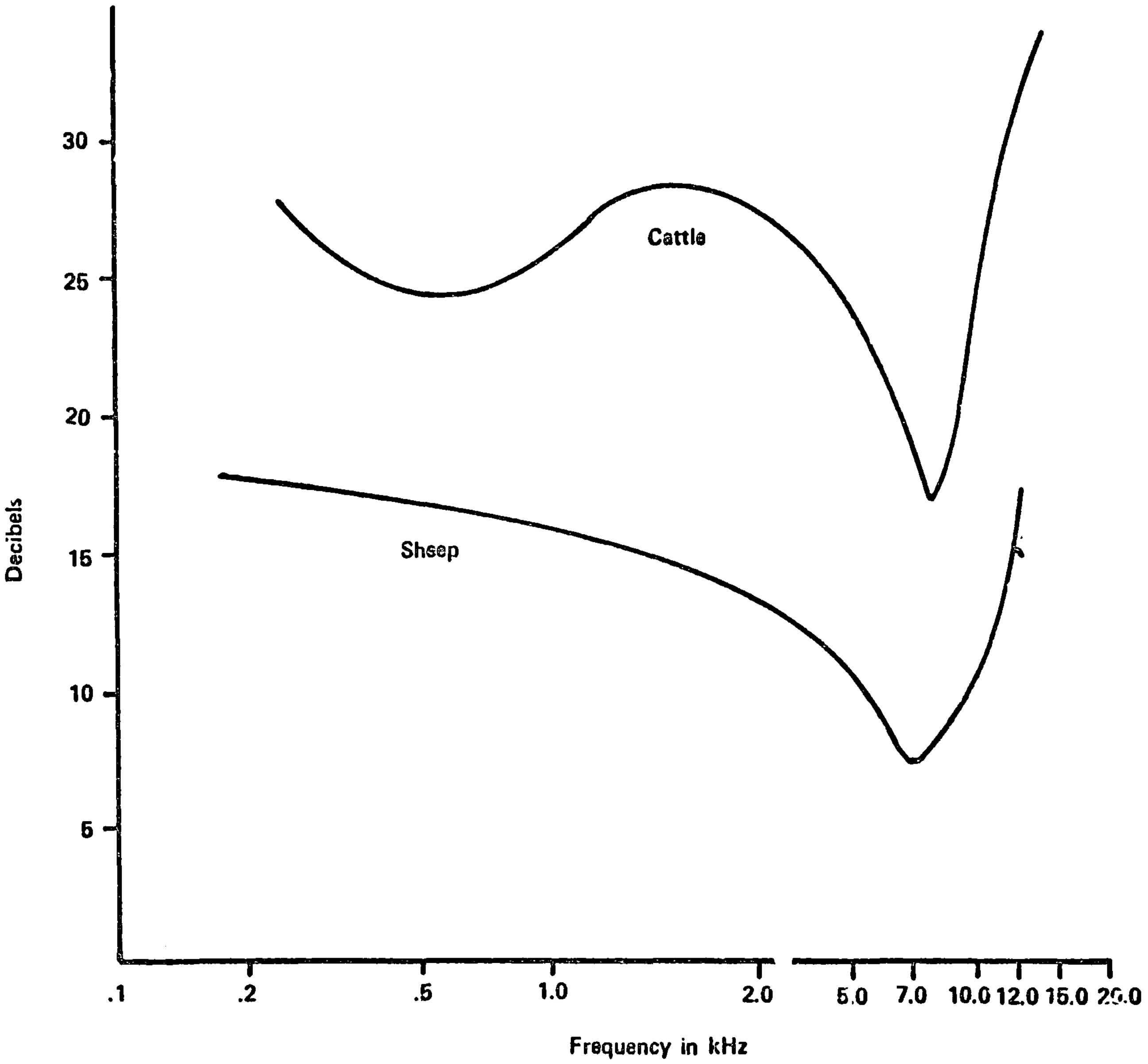

FIGURE 2. Audiogram for Cattle and Sheep (Ames, 1974)

# PHYSIOLOGICAL AND BEHAVIORAL EFFECTS IN FARM ANIMALS

## SWINE

Since farm animals are often exposed to aircraft flyover noise, the adverse effects of such noise have been of concern to farmers and some researchers. A major series of investigations of swine was conducted by Bond, et al. (1963). These investigations explored the physiological and behavioral effects of noise as a stressor. The parameters measured include heart rate, water and sodium balance, weight gain, feed utilization, hormonal secretions, reproductive effects, and general behavioral (fright) reactions. One series of tests used a telemetric electrocardiograph to monitor each pig's heart rate in an acoustical chamber. After a constant heart rate was observed, the experiment was begun. Test recordings of heart rate were made during 15 seconds prestress (quiet), 15 seconds of noise exposure, and 30-second quiet recovery period. The noise stress consisted of taped aircraft at levels of 100 to 130 decibels. The heart rate tests were run at least 4 or 8 times on each animal. Thirteen pigs never exposed to loud noise prior to the test were used in one series. The results showed that heart rate increased significantly due to noise and decreased 30 seconds after the noise stimulus ended, although it had not returned to baseline levels.

The same investigator (Bond, et al., 1963) gave prior exposure to noise to another group of pigs as part of the study. This exposure consisted of a tape of jet aircraft noise at 120 decibels, 12 hours daily for 98 days. Heart rate increased significantly when five of these pigs were exposed to the same taped jet aircraft noise. Previously unexposed pigs were found to have a greater change in heart rate at sound frequencies of 400, 1000, and 2000 Hz (at 110 to 120 decibels). Since the authors state that only small numbers of pigs were given the various treatments, generalizations about correlations between sound level and frequency and degree of heart rate response must be made cautiously.

Other physiological effects on swine were studied in a review of the literature on the physiology and behavior of farm-raised animals. Bond (1970) stated that several days of 93 decibels noise of unspecified frequency resulted in aldosteronism (excess secretion of the hormone aldosterone by the adrenal glands) and severe retention of water and sodium in young, castrated, male pigs. Aldosterone is a steroid hormone responsible for the body's electrolyte (for example, sodium, magnesium, calcium and potassium) balance. Excess aldosterone can 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), muscular weakness (due to decreased potassium), excessive urination, and thirst. These effects are just part of the complex chain of events triggered by stress in an animal, as discussed in the Appendix. The review by Bond (1970) also stated that "alarm signals" recorded from pigs in the slaughter house disturbed the pigs more than mechanically produced sounds, as one might expect.

Besides aldosterone secretion, feed efficiency and weight gain of fattening pigs due to aircraft noise were investigated by Bond et al. (1963). Three to five groups of four to six pigs each were exposed to recorded aircraft noise at 120 to 135 decibels 12 hours daily from around weaning to slaughter at 200 pounds body weight. Each group of pigs included a control group unexposed to noise. No significant differences between noise-exposed pigs and control were observed with respect to feed utilization, rate of weight gain, or food intake.

Reproductive effects in swine were studied by exposing three sows to recorded aircraft flyover noise in an acoustic chamber for 12 hours daily for three days prior to parturition (Bond et al., 1963). No adverse effects were observed on either parturition or the young, although the piglets from the noise-exposed (test) sows were heavier than control piglets. Since the litters from only 3 sows (22 piglets raised) were examined, these weight differences between the test and control piglets are probably due to individual differences and not to noise.

Bond, et al. (1963) also studied the effects of sounds of varying frequencies from 104 to 120 decibels (including the recorded squeal of a pig) on swine behavior. Nursing sows, baby pigs, and adult pigs during mating were observed to show initial alarm followed by rapid indifference to the noise.

In summary, Bond and co-workers consider that swine are able to tolerate, and even become accustomed to, noise up to at least 120 decibels. The only evidence that noise causes stress in pigs is a temporary increase in heart rate. More research is needed before the true effects of noise on swine can be determined.

## CATTLE

The effects of noise on milk production was studied in 182 milk cow herds within 3 miles of eight Air Force bases using jet aircraft. In the one-year study, no differences in milk production were found when compared to herds which were not exposed to the aircraft noise. Also, no differences were found between herds close to the end of the runway and those farther removed (Parker and Bayley, 1960).

Such milk production studies may be affected by sonic booms. Casady and Lehmann (1966) found, over all, few abnormal behavioral reactions in large animals due to sonic booms. However, they reported that their studies conducted on herds of milk cows at Edwards Air Force Base may have been biased, in that the animals used had been exposed to 4 to 8 sonic booms a day for several years. Therefore, even though the intensity of the booms used during testing was higher than those the cows heard daily, the cattle may have already become accustomed to the noise before the actual testing began. Thus, cows may be able to habituate to certain noises, as was the case for swine.

Bond (1956) in his review of the literature on noise effects of man and lower animals, stated that the cows exposed to exploding paper bags every few seconds for 2 minutes during milking did not give milk while the sound stimuli were present. Thirty minutes following the sound stimulation, 70 percent of the normal milk production occurred. Bond also stated that motorboat noise produced a decrease in milk production. However, calf and heifer growth was unaffected by motorboat noise. Bond also reported that observers found a mild reaction in dairy and beef cattle to only 19 out of 104 sonic booms of 2.6 to 0.75 pounds per square foot. Milk production was unaffected during the test period. In fact, Bond noted that reactions to low subsonic aircraft noise were more pronounced than were reactions to sonic booms. Further, the same reactions were observed in response to flying paper, strange persons, or other moving objects. This observation may indicate that such fright reactions occur more strongly when the animal sees rather than hears the object (Fletcher, 1971).

## SHEEP

The cardiovascular and respiratory responses of lambs to noise were examined by Ames and Arehart (1972) by exposing the lambs to three types of auditory stimuli. The stimuli used were white noise, instrumental music, and intermittent miscellaneous sounds (IMS), presented at 75 and 100 decibels sound pressure level. Taped sounds of electric motors, diesel engines, jet and propeller aircraft, cannons, rain, band marches, stadium crowds, fog horns, fire crackers, roller coasters, and machine guns were all used during the IMS exposure. The total noise exposure per day was 11 hours. Each noise stimulus had a duration of from 15 seconds to three minutes, with quiet periods lasting from 1 to 15 minutes between stimuli. The study was divided into 4 periods: (1) a 21-day quiet control period at a 45 decibel ambient noise level; (2) a 12-day test period at 75 decibels; (3) a 2-day control period at 45 decibels; (4) a 12-day test period at 100 decibels. Five lambs, not previously exposed to noise, were added as nonacclimated controls in the third period. During the first day of each 12 day test, heart and respiration rates were measured immediately before each noise exposure, then at 15 minutes, 1, 4, and 8 hours post-stimulus. Daily readings were then taken during the remaining 11 days.

Variations in heart rate occurred earlier and were greater for the 100 decibel exposed nonacclimated lambs with all three sound types. Less heart rate change was observed due to the music exposure than to the other two types of noise, indicating that music was less stressful. Heart rate increased due to both white noise and IMS. Respiration rates increased due to the three types of noise for both acclimated and nonacclimated lambs. The respiratory responses to noise were highly variable and seemed to depend on sound type more than sound level. Panting occurred during both music and IMS exposure. Since the responses were less variable after the 10th day of noise exposure and the preconditioned animals responded differently to noise, acclimation to noise may have occurred. The physiological responses to noise in this study indicate that noise acts as a stressor (can increase the levels of ACTH and other adrenally mediated responses). The responses vary with the type and duration of the noise stimulus. The results are shown in Table 3 and Figures 3 and 4.

The effect of noise of the growth of early weaned lambs was examined by Areheart and Ames (1972). In this study, noise-acclimated lambs were subjected to the previously described stimuli (white noise, music, and IMS) at the same levels (75 and 100 decibels). Their results shown in Figures 5 and 6, indicated that exposure to 75 decibel white noise caused an increase in the animals' weight gain and feed utilization efficiency as compared to either the control groups or the groups exposed to white noise and IMS at 100 decibels. This effect was less pronounced with exposure to IMS at 75 decibels, while music had no effect on growth or efficiency at any sound level. Interestingly, exposure to music, even as loud as 100 decibels, caused the animals to be more "calm, more docile, and generally more tranquil than other groups" (Areheart and Ames, 1972, p. 482).

A final analysis of the data (Figures 5 and 6) shows that both the type of sound and its intensity can significantly affect the growth of early weaned lambs. However, since these findings are based on short-term, or acute, studies, the applicability to long-term, or chronic, exposure conditions may not be possible (Ames, 1978).

## TABLE 3

## Effect of Sound Type and Intensity on Lamb Heart and Respiration Rates[a] (Ames and Arehart. 1972)

| Levels | Types | Heart rate (beats/min.) | Respiration Rate (breaths/min.) |
|---|---|---|---|
| | USASI | 121 ±10.8[b,x] | 43.3 ±5.4[b,x] |
| | Music | 111.7 ±5.6[b,y] | 61.0 ±6.3[c,y] |
| 75 dB | IMS | 119.0 ±15.9[x] | 65.0 ±20.4[c,y] |
| | USASI | 122.0 ±10.4[b,x] | 62.4 ±15.5[c,x] |
| 100 dB | Music | 116.0 ±8.6[c,y] | 44.0 ±4.9[b] |
| Acclimated | IMS | 123.0 ±14.6[x] | 49.0 ±13.3[b] |
| 100 dB | USASI | 130.6 ±13.2[c] | 39.0 ±5.9[b] |
| Non- | Music | 124.0 ±8.3[d] | 45.0 ±5.2[b] |
| acclimated | IMS | 121.0 ±11.3 | 46.8 ±8.3[b] |

[a] Mean and SD of three observations during 12-day test.

[b,c,d] These superscript letters differing in a column indicate significant differences (P<.05) for intensity levels.

[x,y] These letters, differing in a column indicate significant differences (P<.05) for types of sound.

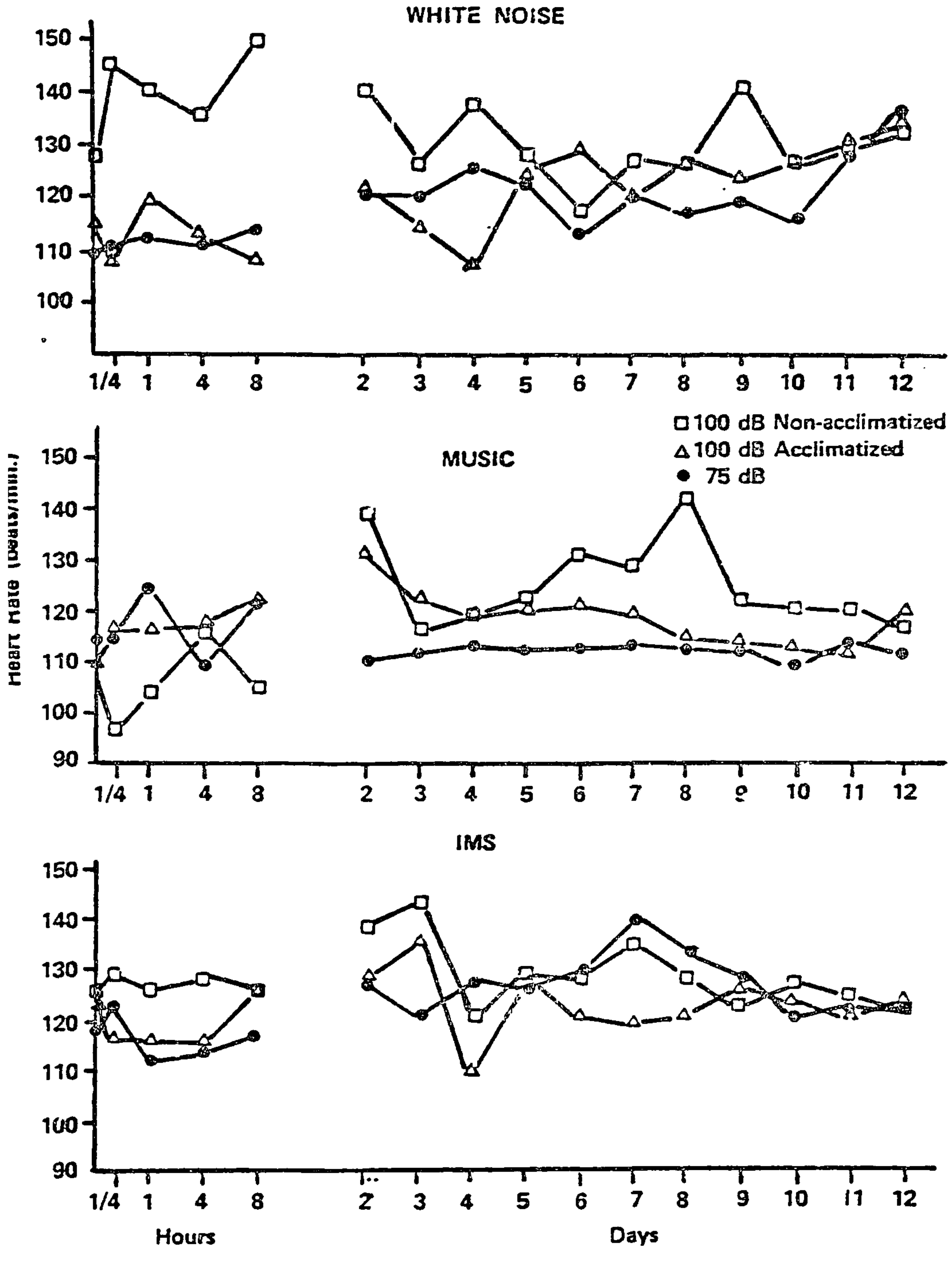

FIGURE 3. Heart rates of lambs exposed to different sound types and intensities. (Ames and Arehart, 1972)

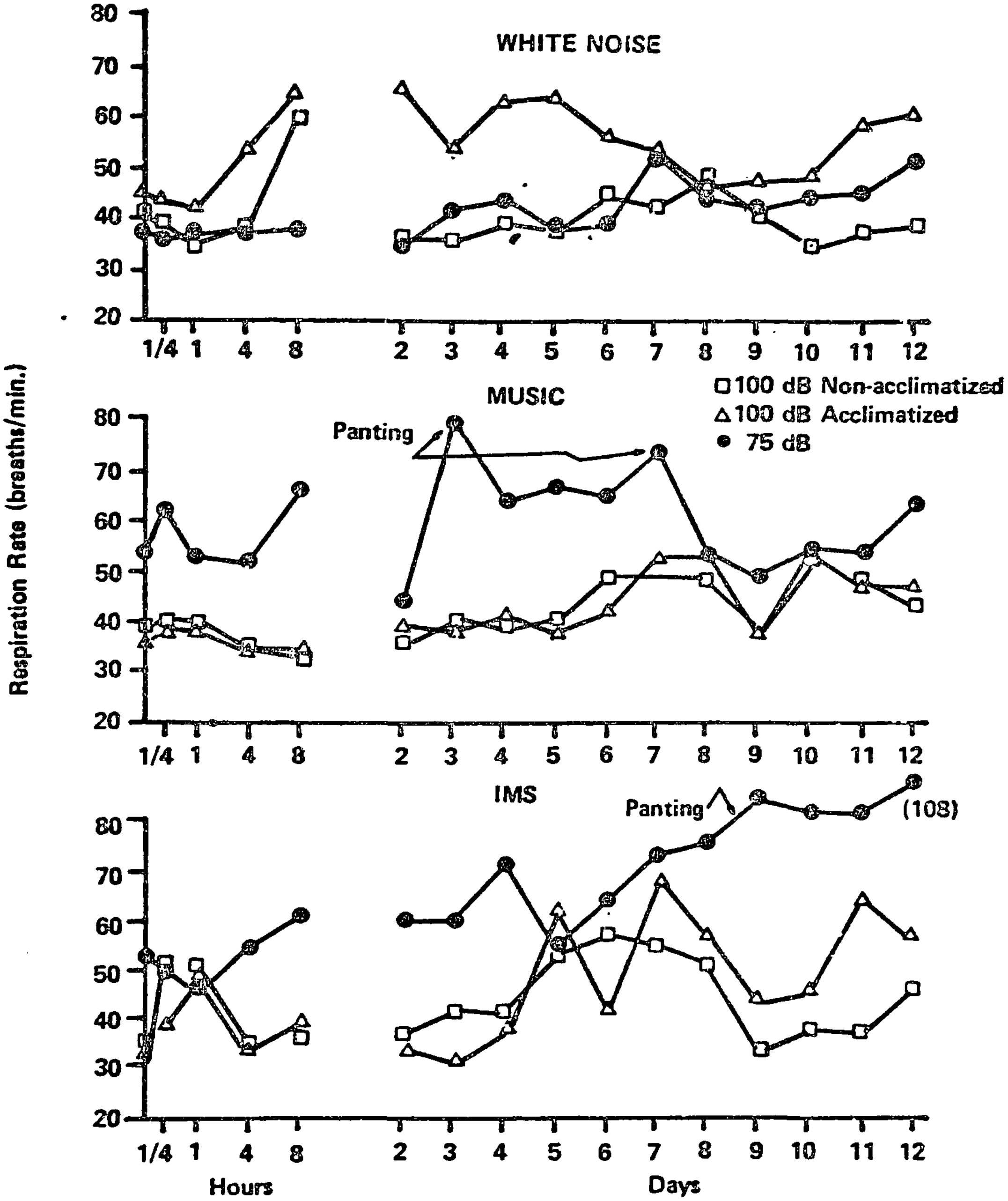

FIGURE 4. Respiration rates of lambs exposed to different sound types and intensities. (Ames and Arehart, 1972)

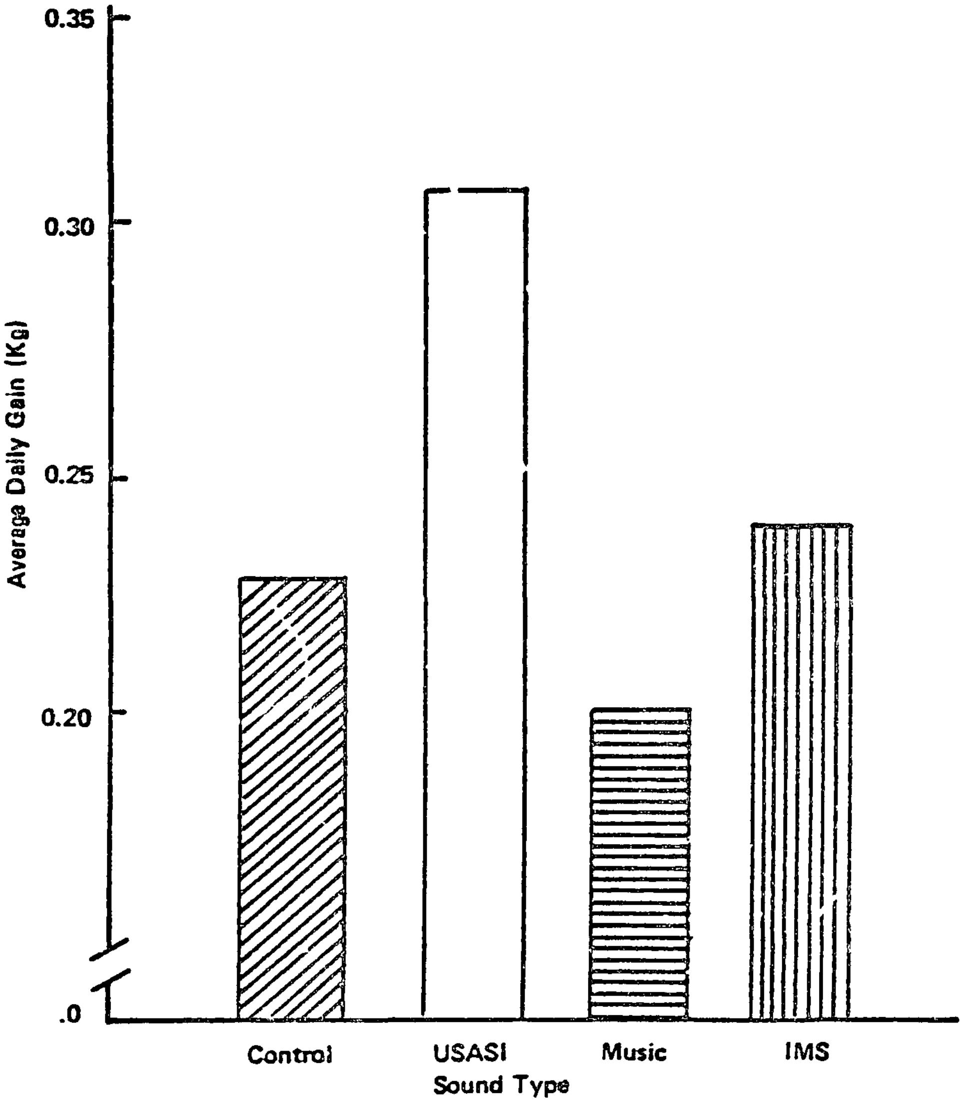

FIGURE 5. Average daily gains of early-weaned lambs exposed to different sound types. (Ames, 1978)

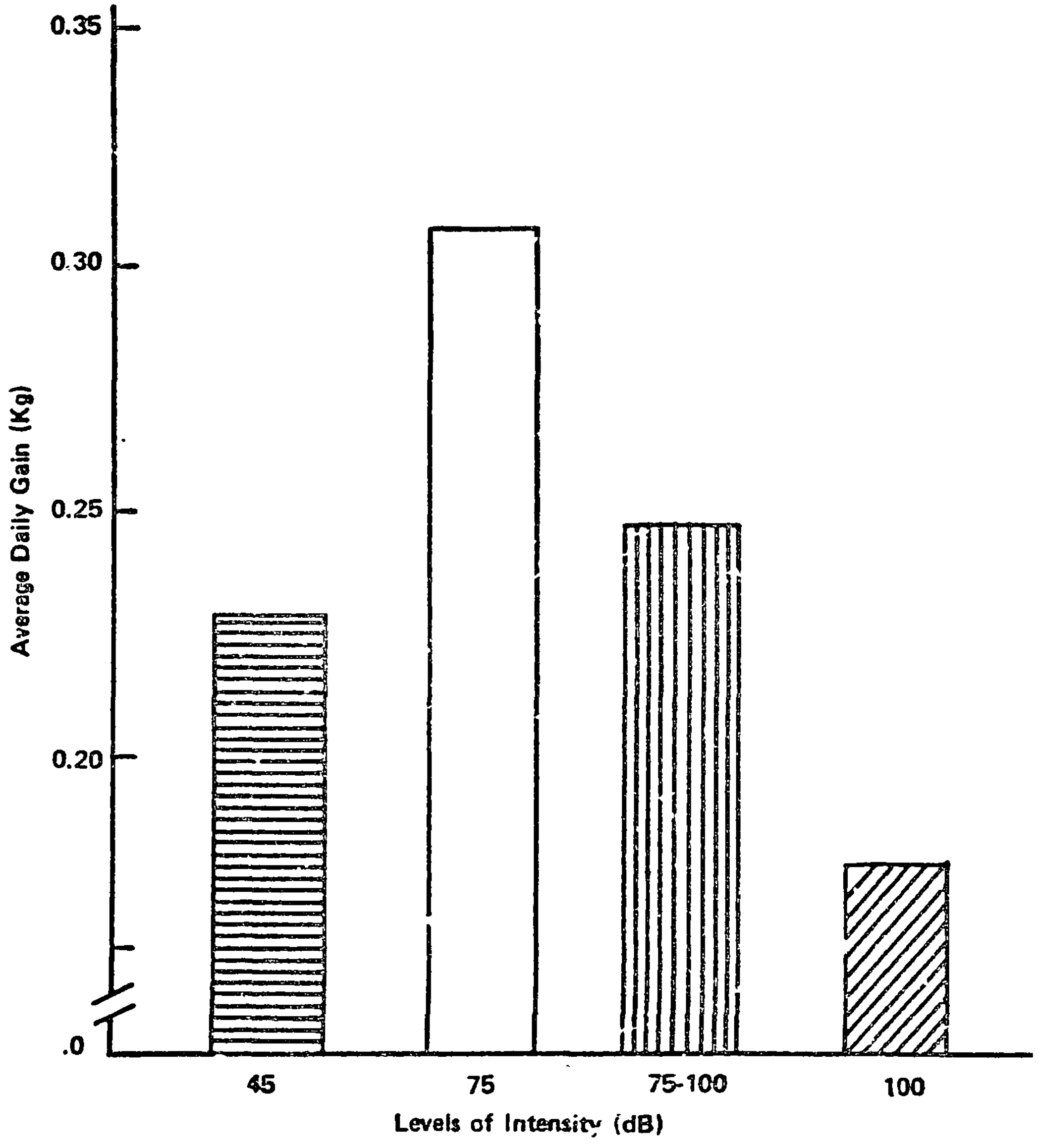

FIGURE 6. Average daily gain of e weaned lambs exposed for 12 day periods to different sound intensities (45 dB Control period, 75-100 dB acclimatized, 75 and 100 dB non-acclimatized). (Ames , 1978)

Ames (1978) also studied the effects of noise on digestive function. It was found that sheep consumed less food in noisy environments than in quiet. In addition, the results showed that for IMS-exposed animals, urinary output was greater than in the controls or the animals exposed to white noise or music. IMS exposure also increased digestibility coefficients (the amount of food absorbed by the digestive system as determined by feces analysis), while music or white noise had no similar effect. It was suggested that neural and endocrine mechanisms are involved in the reactions.

Studies of metabolism and rumen (the first stomach of a cud-chewing animal) were conducted by Harbers, et al. (1975) on four yearling sheep exposed to noise levels and types similar to those used by Areheart and Ames (1972). The 7-day noise exposure trials at 75 or 100 decibels were preceded by control trials at a background level of 45 decibels. The animals consumed less food under all the noise types and levels above background. Water intake, urinary output and metabolizable energy varied with the type (but not intensity) of noise; intermittent miscellaneous sounds (IMS) caused increases in all measures. Digestibility coefficients were also higher with IMS than with the other types and the controls. The highest urinary creatinine (a nitrogenous waste product, the level of which indicates normal kidney function) levels were found due to 75 decibel music exposure. The IMS and white noise produced significantly lower values, indicating reduced protein breakdown. Rumen motility was not affected significantly by the noise, after the initial 15 minutes. The authors conclude that sheep are able to adapt to continuous or intermittent noise of 100 decibels or less. No adverse effects were noted, and IMS even stimulated digestion. It should be pointed out that this too is a short-term study and was not an examination of long-term effects. However, the results make it clear that noise exposure may play an important role in changes in digestive efficiency, metabolic balance, and growth rate. Thus, further research should be undertaken to identify species susceptible to these effects as well as the physiologic basis for this susceptibility.

Ames (1974) found alterations in gonadotropin (reproductive hormone) levels in lambs exposed to 75 and 100 decibel noise levels. Ovarian changes, such as increased numbers of corpora lutea, were produced when ewes were exposed to a 4000-Hz pure tone during proestrus. The ewes later produced significantly more lambs. The author suggests a hypothalamic effect of noise, which alters the gonadotropin releasing factors, resulting in ovarian changes.

Since other stressors, such as heat, shock, and restraint have been shown to produce undesirable color changes in the meat from cattle and pigs, Ames (1978) tested the effects of noise stress on lamb meat. The meat from 42 lambs subjected to various noise stimuli was inspected visually and spectrophotometrically after slaughter. Color changes in the meat were noted with 100 decibel white noise and intermittent miscellaneous sounds. These types of noise were apparently more stressful than music to lambs, using the degree of color change in the meat as the criterion.

## HORSES

Casaday and Lehman (1966) reported some behavioral effects in race horses due to jet aircraft flyovers. The reactions included jumping and galloping around, apparently fright reactions. Such reactions to loud noise are observed in most species of animals, although the degree of fright seems to vary.

## MINK

Cottereau (1978) stated that he observed little or no effects of sonic booms on ranch-raised mink in spite of the fact that some studies have reported severe reactions. It should be noted, however, that mink may be overly sensitive to certain types of other sounds.

In one study (Travis, et al., 1968), 120 mink were exposed to simulated sonic booms with peak overpressure in the housing shed decreasing from 2.0 pounds per square foot in the front of the shed to 0.5 pounds per square foot in the back of the shed in a smooth gradient. A mean boom frequency of 485 Hz was used. Litter sizes of boomed mink were larger than those born to non-boomed mink. Although the first boom resulted in some apparently curious emergence from nests, no racing, squealing, or other evidence of panic was observed. Autopsies of kits which died of natural causes disclosed no disorders which could be traced to booming.

Another study (Bell, 1970) showed little or no response to six sonic booms in 10 days with reference to mink bitch behavior during breeding, birth of kits, or whelping. No cannibalistic behavior toward kits or any other evidence of panic was observed.

Travis, et al. (1972) exposed mink to real and simulated sonic booms during the whelping season in order to study the effects on late pregnancy, parturition, early kit mortality and kit weight at 7 weeks. One group was subjected to three real or three simulated sonic booms at a pressure of 290 $N/m^2$ (Newtons per square meter; approximately 145 decibels), while a control group was not exposed to any booms. The findings indicate that farm-raised mink exposed to intense sonic booms during whelping season showed no adverse reproductive or behavioral reactions.

## POULTRY

Stadelman (1958a) held fertilized eggs from white hens 1 to 7 days after laying and then subjected them to incubation under conditions of noise (over 120 decibels) or no noise (under 70 decibels). The noise produced inside the incubation boxes consisted of playbacks of recorded background airfield noises, and noise from propeller and jet aircraft. Noise was present 8 out of every 20 minutes from 8 a.m. to 8 p.m. each day and from 8 p.m. to 8 a.m. every third night. The results showed no effects on hatchability of eggs or on the quality of chicks hatched.

Vince (1966) exposed embryonic chicks to artificial "peeps" which mimicked the "peeps" actually emitted by bobwhite quail chicks. The artificial "peeps" were speeded up or slowed down as a function of the rate of speed at which the actual peeps were emitted. Three or more peeps per second were instrumental in causing eggs to hatch whereas less than three peeps per second did not increase hatchability of eggs.

In another study (Bell, 1970), it was shown that exposure to daily sonic booms with sound pressures of 0.75 to 1.25 pounds per square foot had no adverse effects on the hatchability of chicken eggs exposed for 21 days during incubation.

Besides egg hatchability, the effects of noise on hen maternal behavior have also been investigated (Stadelman, 1958a). Eighteen New Hampshire and Plymouth Rock hens were observed for broodiness for three days and then divided into two groups. Broodiness is defined as the cessation of egg laying and the onset of egg incubation. One group was exposed to noise at 120 decibels while incubating 12 hatching eggs each. Hens in the other group were given 12 hatching eggs each but were not exposed to sound. In the group not exposed to sound, all eggs were hatched. In the group exposed to sound, all except one hen stopped brooding within two hours. The exceptional hen, although she remained broody, hatched only one chick from 12 fertilized eggs.

Stadelman (1958a) also reported that recorded aircraft flyover noise at 80 to 115 decibels (played daily from 8 a.m. to 8 p.m. and from 8 p.m. to 8 a.m. every third night for 5 out of 20 minutes from onset of brooding until chicks were 9 weeks old) resulted in no difference in weight gain, feeding efficiency, meat tenderness or yield, or mortality between noise-exposed and unexposed chicks. It was noted, however, that the chicks subjected to the noise were observed and that the presence of the observers could have rendered these chicks more adaptable to changing situations than chicks raised under natural conditions.

The effect of noise on broodiness has also been studied in turkeys (Jeannoutot and Adams, 1961). Seventy-eight turkeys were exposed to recordings of low flying jet planes at 110 to 135 decibels for 4 minutes in the third day of broodiness. This exposure typically resulted in a cessation of broodiness and a resumption of egg laying. The period between cessation and resumption of egg laying was shorter than when interruption of broodiness was produced by injections of hormones such as progesterone. In addition, hens injected with progesterone showed a reduction in egg production during resumption of egg laying, whereas the noise exposure of broody hens produced no decrease in egg laying when egg laying was resumed following sound stimulation.

In another experiment by Stadelman (1958b) 2,400 crossbred meat chicks were exposed to aircraft flyover noise at 80 to 115 decibels. The chicks were not exposed to sound until they were 31 days old, at which time they were exposed for 5 out of every 20 minutes for 4 hours. Chicks were not exposed to the noise again until they reached 45 days old. The noise exposure schedule above was then reinitiated, with a three-day break due to equipment failure, until they reached 10 weeks old. There was no difference in weight gain or feeding efficiency between exposed and nonexposed chicks. One chick was trampled to death when noise was initiated at 31 days and chicks ran away from the speaker at the end of the cage where the sound level was 20 decibels lower. The investigators hypothesized that during an actual flyover, the sound would not be louder at one end of the pens than the other; therefore, there would be no running from the sound source.

## SUMMARY

The effects of noise on domestic animals are not as well-documented as those on laboratory animals. Nevertheless, there is evidence that excessive noise could have very disruptive effects on certain normal activities of animals that are important sources of food. The major observed effects of noise on domestic animals from the preceding studies are summarized below:

- Initial fright or alarm reactions in all species
- Significant temporary increases in heart rate in lambs and pigs

- Increased respiration rate in lambs
- Decreased milk production in cows exposed to certain unpleasant noises (motorboats and exploding paper bags), but not sonic booms
- Increased weight gain and feed utilization but decreased feed consumption, in sheep
- Changes in sheep water intake, urinary output, metabolizable energy, digestibility coefficients, and urinary creatinine levels of sheep due to intermittent miscellaneous sounds (75 and 100 decibels).
- Alterations in ovarian factors and reproductive hormone levels in lambs
- Ability to tolerate noise levels up to 120 decibels in pigs, sonic booms in cows, and 100 decibel noise or lower in lambs
- Color changes in lamb meat with exposure to 100 decibels white noise or IMS
- Inhibiting effects on hen maternal behavior (broodiness) due to 120 decibels or greater aircraft noise, resulting in fewer eggs hatched.

Although there is a general trend for domestic animals to be able to become used to intermittent noises under 120 decibels, this ability has not been demonstrated with all types of environmental noise conditions. Poultry are known to have severe fright reactions to loud noise (Cottereau, 1978), which could adversely affect egg production. Since noise and other stressors can produce unacceptable color changes in meat for human consumption from cattle, pigs, and lambs, the economic consequences of excessive noise could be severe. More research on the effects of noise on food quality needs to be undertaken.

Not only can noise affect the quality of food from domestic animals, but also noise has produced changes in growth, reproductive physiology and behavior, metabolism, and other physiological parameters. These changes are not all unfavorable, since lambs exposed to 75 decibels white noise had increased growth rates over 100 decibel noise or control conditions. Since growth hormone and many other hormones are released during stress (Vander, et al., 1975), the mechanisms of noise effects on growth are probably very complex. Ames (1978) suggested a neural response to noise that triggers endocrine reactions, but more research is needed before these responses are understood.

# SECTION III. WILDLIFE

## INTRODUCTION

The wildlife studies discussed in this section cover a wide range of animals, including insects, fish, reptiles, birds, and mammals. Although many studies have been done on the effects of noise on animals, few long-term studies performed in natural settings exist. Those that are available are often lacking specific information concerning noise intensity, spectrum, and duration of exposure. For a discussion of the importance of adequately specifying the noise exposure and factors related to sound propagation and detection, see Harrison (1978).

The bulk of the studies emphasize behavioral effects of noise on wildlife, because such effects are often most readily observable (Lee and Griffith, 1978). Although behavioral responses are useful indicators of noise effects in animals, there is a potential problem in the interpretation of these reactions because it is often subjective. Many species have been studied in depth for response patterns to noise, as in the Preyer reflex discussed in the section on laboratory animals. An important area of noise research in wildlife that has been neglected is a description of the relative hearing sensitivity of each of the many wildlife species. This is obviously necessary for evaluating and predicting the effects of various noise levels and types. Table 4, constructed by Lee and Griffith (1978) from various sources, summarizes some of the available data on hearing sensitivities in wildlife species and humans.

As the table shows, some wildlife species are sensitive to a greater sound frequency range than humans. The A-weighting scale measures sound levels by selectively discriminating against certain low and high frequencies. The frequency of the sound is a determinant of loudness as perceived by the listener. The A-weighted scale represents a simplification of the response pattern in humans. Since wildlife species do not have the same response pattern as humans, A-weighting may not be appropriate for many wildlife studies. Fletcher (unpublished) suggested using the unweighted sound pressure level until more appropriate scales for animals are determined.

Another potential effect of noise on wildlife is masking. Masking is interference with communication or signals and is a common problem for humans as well as wildlife. When masking occurs, the threshold of hearing for a desired sound is increased due to the presence of an undesired sound. Animals use auditory signals to evade predators, to locate mates, their young and prey, and to define territories. Even a wildlife species which is adapted (behaviorally or physiologically) to loud noise could be adversely affected if its communications patterns are disrupted.

Masking due to noise has been studied in wildlife by comparing the level and spectra of (1) the ambient or background noise in the natural habitat, (2) the offending noise, and (3) the signal or communication. For example, Figure 7 shows the spectrum of each type of ambient noise in an Australian habitat (Rennison and Wallace, 1976).

Another neglected area of noise research on wildlife is that of nonauditory physiological effects. The nonauditory effects have been more thoroughly studied in humans and in laboratory animals. Many of these effects involve the startle or stress reactions (increased cortisol levels

## TABLE 4. Hearing Abilities (Frequencies) of Various Animals as Compared with Man (Lee and Griffith, 1978)

| Species | Lower Limit (Hz) | Maximum Sensitivity (Hz) | Upper Limit (Hz) |
|---|---|---|---|
| Man<br>(*Homo sapiens*) | 16 | 4,000 | 20,000 |
| | Invetebrates | | |
| Tiger moths 1/<br>(*Arctiidae*) | 3,000 | -- | 20,000 |
| Noctuid moth 1/<br>(*Prodenia evidania*) | 3,000 | 15,000-60,000 | 240,000 |
| Butterflies<br>(38 species) 1/<br>(*Lepidopterae*) | -- | 40,000-80,000 | -- |
| Long-horned grasshoppers 1/<br>(*Lepidopterae*) | -- | 40,000-80,000 | -- |
| Long-horned grasshoppers 1/<br>(*Tettigoniidae*) | 800-1,000 | 10,000-60,000 | 90,000 |
| Field cricket 1/<br>(*Gryllus*) | 300 | -- | 8,000 |
| Mosquito 2/<br>(*Anopheles subpictus*) | 150 | 380 | 550 |
| Male Midges 2/<br>(*Tendipedidae*) | 80-800 with peaks at 125 and 250 | | |

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1/ Frequencies of continuous tones that stimulate the tympanal organs.

2/ Frequency response of Johnston's Organ which is located at the base.

TABLE 4. (cont.) Hearing Abilities (Frequencies) of Various Animals as Compared with Man

| **Species** | **Lower Limit (Hz)** | **Maximum Sensitivity (Hz)** | **Upper Limit (Hz)** |
|---|---|---|---|
| **Amphibians** | | | |
| Bullfrog (*Rana catesbeiana*) | <10 | <1,800 | 3,000-4,000 |
| **Birds** | | | |
| Starling (*Sturnus vulgaris*) | <100 | 2,000 | 15,000 |
| House sparrow (*Passer domesticus*) | -- | -- | 18,000 |
| Crow (*Corvus brachyrhynchos*) | <300 | 1,000-2,000 | >8,000 |
| Kestrel (Sparrow Hawk) (*Falco sparverius*) | 300 | 2,000 | >10,000 |
| Long eared owl (*Asio otus*) | <100 | 6,000 | 18,000 |
| Mallard duck (*Anas platyrhynchos*) | 300 | 2,000-3,000 | >8,000 |
| **Mammals** | | | |
| Bats (*Chiroptera*) | <1,000 | 30,000-100,000 | 150,000 |
| Rodents (*Rodentia*) | <1,000 | 5,000-18,000 & 40,000-60,000 | 100,000 |
| Cats (*Felidae*) | -- | -- | 70,000 |
| Opossum (*Didelphus virginiana*) | <500 | -- | >60,000 |

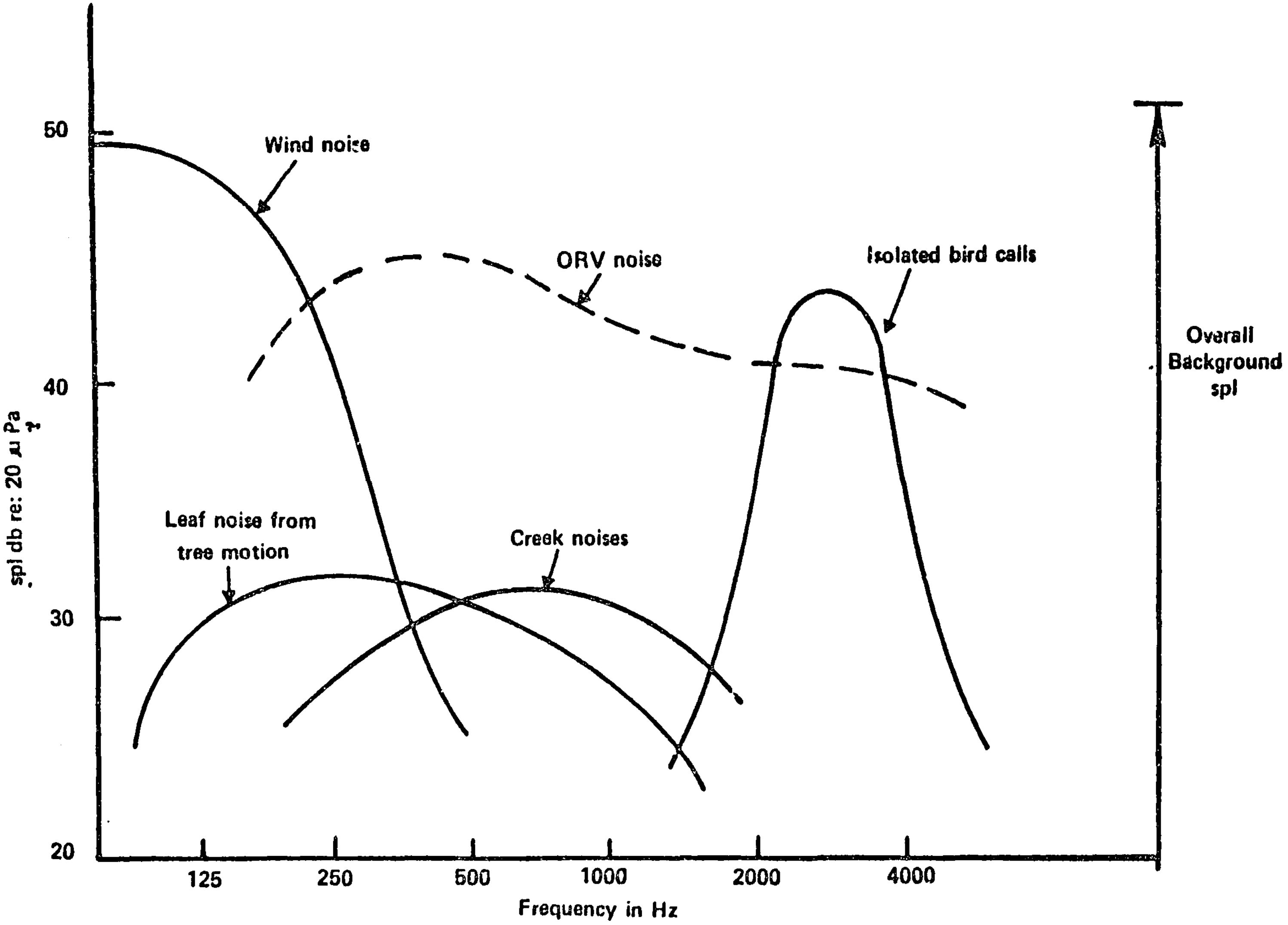


FIGURE 7. Frequency Spectra of Background Noises and Off-Road Vehicle (ORV) Noise in an Australian Habitat (Rennison and Wallace, 1976)

and other sympathetic nervous activity) described in the Appendix. Wild animals that can survive human encroachment on their habitats have been able to adapt their behavior patterns and other responses to human civilization. Busnel (1978) lists examples of animals which have successfully adapted: rats, mice, crows, pigeons, starlings, and seagulls, all of whom choose to live near humans to take advantage of the food supply and shelter. Many insect species, too numerous to mention here, have certainly prospered due to humans. Some of the "semi-domestic" animals, such as cockroaches and house mice, are pests. Squirrels and racoons are considered pests by some, because they raid bird feeders and garbage cans. Possibly, the true nature-lovers among us would rather have these animals around, since they are interesting and occupy a valuable place in our ecosystem. Many insects, such as honeybees, praying mantis, and ladybugs (who feed on aphids), are more than just part of our ecosystem; they are highly beneficial.

Although there are species which have apparently adapted to human noise, these are mainly smaller species living fairly close to humans. The larger animals that risk becoming endangered, such as bears, caribou, the African game animals, and eagles, are of great concern to many people today. The environmental impact studies conducted for the Canadian Arctic Gas Pipeline are an example of this concern and will be discussed in detail in this section.

The behavioral responses of animals to noise are related to their reactions to the humans who are directly or indirectly responsible for the noise. For example, if an animal sees a person shooting a gun or riding a snowmobile, it will react to both the noise and the person. If the animal is wild, such as a reindeer, it will be frightened of humans. A domestic animal, such as a hunting dog, would probably not be afraid of either the person or the noise. Care should be taken in interpreting animal responses as to whether they are elicited by the noise itself or by the noise as a signal of another threat.

The wildlife species to be discussed in this section are presented by major groupings: mammals, birds, reptiles, amphibians, fish, and insects.

## MAMMALS

### HEARING

Studies on the effects of noise on hearing in mammals are scarce for wildlife species, but some quantitative data are available on some desert animals and a few species of marine mammals (Myrberg, 1980).

Aquatic habitats are increasingly being recognized as vital to our ecosystem and are used as sources of food and many raw materials, for recreation and transportation, as sites for various industries that need water, and (unfortunately) for the disposal of wastes. The aquatic environment is a unique one, containing some of the most interesting and beautiful of creatures. Of the two basic aquatic habitats, fresh water and marine, the latter has attracted the most public interest in recent years. This is partially due to the many still unknown aspects of the oceans and partially because salt water covers over 70 percent of the earth's surface (Knight, 1965).

Marine mammals tend to be very sensitive to high frequency sound. The major sound sensitivity ranges are from 500 Hz to 45 kHz for the seals and sea lions and from 8 kHz to 145 kHz for the porpoises, dolphins, and toothed whales. The specific animals on which much of this information is based include the harp seal, the harbor seal, the California sea lion, the bottlenose dolphin, the harbor porpoise, the common porpoise, and the killer whale.

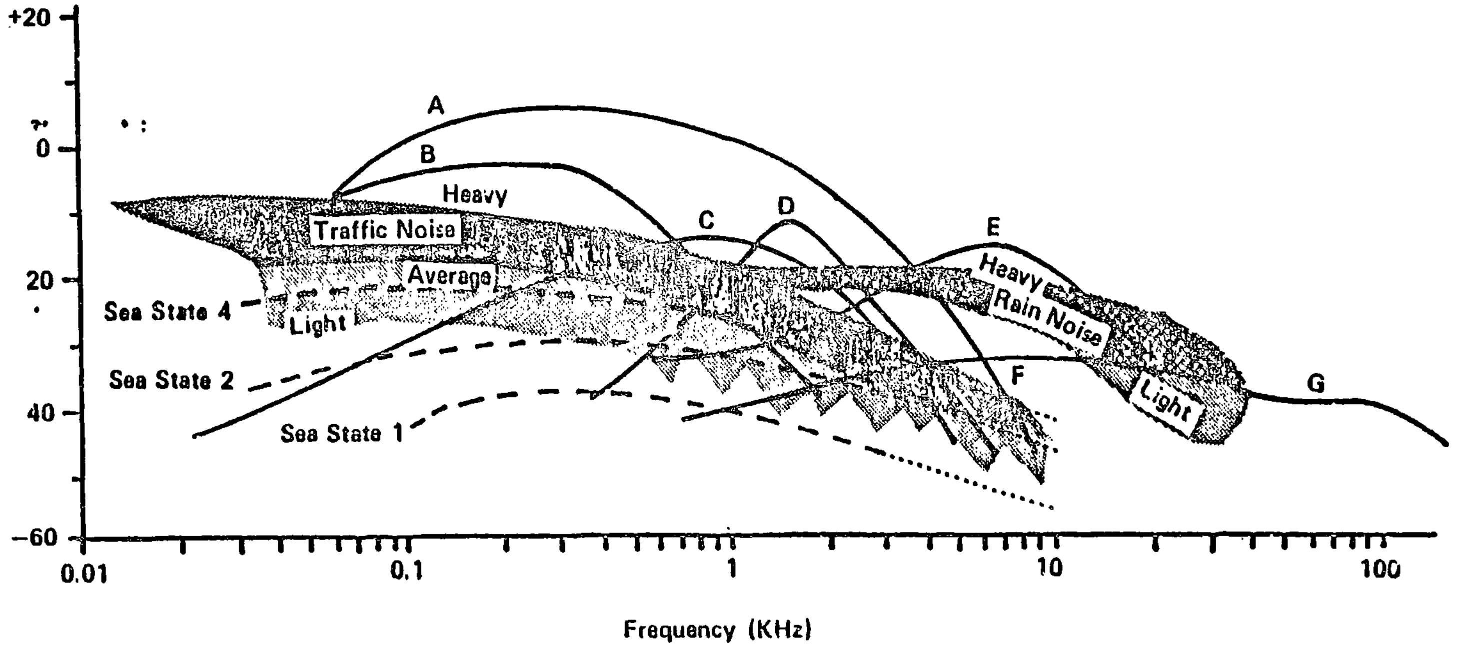
The most sensitive auditory frequency region for these animals parallels that of the sounds made by them. These sounds have been of great interest in recent years especially regarding the dolphins and toothed whales (odontocetes) and the humpback whales. The most studied sounds made by the odontocetes are called echolocation clicks. Echolocation is the location of distant or invisible objects using reflected sound waves. Another type of sound, humpback whale songs, are so musical they have been recorded and sold for recreational listening. These sounds are considered to be a complex communication device which is not well understood.

The acoustical system of marine mammals and other aquatic mammals is their most important distance receptor system, and it furnishes important information regarding food, mates, and predators (Myrberg, 1980). Thus, anything that affects the hearing of these animals has potentially harmful effects on the species. Myrberg has suggested that excessive ambient noise may affect both perception and sound production in marine mammals. A further discussion of these effects is included in the sections on behavior and masking in mammals.

The world under the sea is not a silent place. Sources of ambient noise include vocalizations from marine animals, rain, traffic of marine animals, ships, and other aquatic vehicles, industrial noises, and military noises. Myrberg (1980) constructed Figure 8 for his review of the effects of noise on marine life. He stated that the major habitat of the marine mammals is in shallow, coastal areas; thus, the figure includes noise levels at a depth of less than 70 meters. (Note: The underwater reference sound pressure in Figures 8 through 13 and in Table 5, all from Myrberg (1980), is 1 microbar, which is equivalent to 1 dyne per square centimeter. 0 dB re 1 microbar is equivalent to 100 dB re 1 micropascal.)

The other group of wild mammals whose hearing has been studied are the small desert animals in the Southwestern United States. One of the noisier human sports is motorcycle racing. Some researchers at California State University (Gibson, et al., unpublished) became interested in the effects of motorcylce racing on small desert mammals. Small animals were sampled both before and after an excessively noisy race, in which A-weighted sound levels near the pit were intermittently over 120 decibels for ten hours. Sound levels reached 140 decibels for brief periods. Animals trapped after the race were bleeding from the ears and nose, indicating trauma to the auditory system had occurred. The researchers then investigated whether the noise level inside the burrows of these animals was any lower. Using a Honda 100 cc motorcycle as the noise source, a special sound probe was introduced into the burrows. Sound levels inside the burrows were measured both with the entrances open and closed with sand. Noise levels inside the burrows were only slightly less than those outside, so that the animals were not easily able to escape the noise.

Another study on desert mammals (Bondello and Brattstrom, 1979c) has produced some evidence that off-road vehicle noise can disrupt the predator-prey relationship between the desert kangaroo rat (Dipodomys deserti) and the sidewinder rattlesnake (Crotalus cerastes). One behavior of the kangaroo rat when a predator approaches is "sand kicking," i.e., the rat turns away from the predator and kicks sand in its direction as the rat departs. This behavior can be elicited in the laboratory either by presenting a rattlesnake



**Examples of Biological Sources of Sustained Ambient Noise**

A. Croaker Chorus.
B. Croaker Chorus.
C. Sea Trout Chorus.
D. Evening Chorus-Attributed to Sea Urchins
E. Snapping Shrimp on Sponge Bed.
F. Snapping Shrimp on Sponge Bed.
G. Snapping Shrimp on Sponge Bed.

FIGURE 8. Shallow water (<70 m), ambient noise (spectrum level). Data have been extracted from numerous sources and redrawn. (Myrberg, 1980)

visually to the rat or by playing the noise of a crawling rattlesnake (at an A-weighted sound level of 36 to 38 decibels at 10 centimeters) to the rat from a tape recording. In this study the rat was selective, responding with sand kicks to the sound of the sidewinder but not to the sound of static or a hum. Two rats out of 14 were selected for their consistent sand-kicking behavior. When typical dune buggy sounds (95 decibels, A-weighted, at 4 meters) were played to the rats for 500 non-continuous seconds (25 seconds on, 5 seconds off), their hearing acuity was impaired. Ten minutes after the presentation of the noise dose, the level of the sidewinder noise had to be increased by 8 to 10 decibels before the rat detected it. This corresponded to reducing the distance in the field at which the rats would be able to detect the rattlesnake from 40 centimeters to 2 centimeters. It took the rats nearly 3 weeks to recover their original hearing sensitivity. Thus, for nearly 21 days following the sound exposure, under nocturnal conditions, the rats could conceivably have been approached and successfully struck by the sidewinder rattlesnake.

## MASKING

Masking refers to noise that interferes with communication of auditory signals. Behavioral changes due to masking may be the most observable effects of noise (Lee and Griffith, 1978). Since auditory signals are used in locating mates, to establish territory, for orientation, migration, catching prey, sound detection and many other functions, masking could have profound secondary effects on mammalian behavior. The importance of communication signals has recently been studied in Old World monkeys (genus Macaca) by Brown, et al. (1978).

Indirect effects of masking may also be produced, due to the fact that all the animals in a habitat or ecosystem are interrelated. Thus, an animal that is directly affected by noise may affect another species, which may at first appear unaffected. For example, predator-prey relationships between the wolf and the caribou may be upset by noise connected with construction of the arctic gas pipeline. Although the wolf population does not seem to be in jeopardy from noise, the caribou may be affected. If the caribou population were to diminish due to noise, the wolf population, which feeds largely on caribou, could also decline (Kucera, 1974).

Dooling, et al. (in press) hypothesized that one way to predict the species most vulnerable to masking effects is on the basis of the frequency range of sounds made by the animal. Two groups of mammals which are known to depend on auditory signals for survival are bats and the marine mammals.

It has been shown that bats can be resistant to masking (Griffin, et al., 1963). Apparently they can orient themselves so that noise and signals are received from different angles (signal masking is greatest when noise and signal are received from the same direction). This ability represents an adaptive response or coping mechanism.

Masking has also been studied in marine mammals, since auditory signals are important factors in distance reception, finding food and mates, avoiding predators, and locating prey. Whales and dolphins produce many sounds for these purposes. In order to explore the potential for adverse effects of masking on marine mammals, the spectra and intensities of the critical signals, and the spectrum and level of the ambient noise must be determined. Figure 8 displayed some underwater ambient noise levels. Some data from

Myrberg (1980) on potential masking in the sea lion and dolphin are included in Figure 9. The figure shows that rain and ship traffic have the potential to cause masking, although this has not been empirically demonstrated.

Another way of gauging effects of masking noise is by estimating the maximum distance at which an animal can detect a sound made by another member of its species, under various noisy conditions. Since ambient noise levels in the sea can be great enough to mask sounds important to marine mammals, a number of studies have considered the effects on signal detection of rain, ship traffic, and wave action (sea state). Sea states 1 and 2 are calm and moderate, respectively. Table 5, from Myrberg (1980), gives the estimated maximum sound detection distances for the common (or harbor) seal (Phoca vitulina) under different marine ambient noise conditions.

As Table 5 shows, rather calm seas, rain, and ship traffic may considerably reduce the distance over which a seal can hear sounds from another seal. Since intraspecies communication is very important to marine mammals, more studies should be conducted on the effects of man-made noises in the sea, such as those from oil rigs, factories, and ships.

Another study of masking of auditory communications was conducted with regard to the fine whale. The fine whale reportedly uses 20 Hz signals for communication over as many as several thousand miles. This whale species forms social units, or range herds, which are apparently spread out over large areas in the sea. The major underwater sources of noise for these animals is ship traffic, in the range of 10 to 500 Hz. The investigators, as reported in the review by Shaw (1978) suggested that this ship noise may have reduced the whales' communication distance. The long term effects of such reduction in communication on this species are unknown.

## NONAUDITORY PHYSIOLOGICAL EFFECTS

Very little work has been done on the nonauditory physiological effects of noise on wildlife. However, certain of these effects have been demonstrated in laboratory animals (see Section I). Therefore the potential may exist for similar effects in wildlife. The effects that have been observed in wild mammals include hormonal, metabolic, and reproductive effects. Damage may be produced through stress reactions, which can be caused by noise as well as other noxious agents.

A study on the reaction of caribou to noise was done as part of a series of environmental impact statements on the proposed Canadian gas pipeline. Calef (1974) noted that any unfamiliar stimuli, such as human activities, can disturb physiological functions of these animals. The effects of such disturbances observed in wild and domestic ungulates (hoofed animals) include elevated adrenocorticoid levels, weight loss, increased disease susceptibility, and reproductive effects such as lower birth weights, increased resorptions (fetal reabsorptions) and abortions (miscarriages). Although aircraft flying more than 500 feet overhead usually do not produce any overt reactions in caribou, Calef stated that physiological stress responses may still be induced.

Another mammal for which there is limited research on the physiological effects of noisy human presence is the white-tailed deer. Moen (1976) investigated the adaptive responses of deer to cold stress during winter, by observing deer behavior. Between January and early March, deer tend to conserve thermal and other types of energy by reducing their activity and

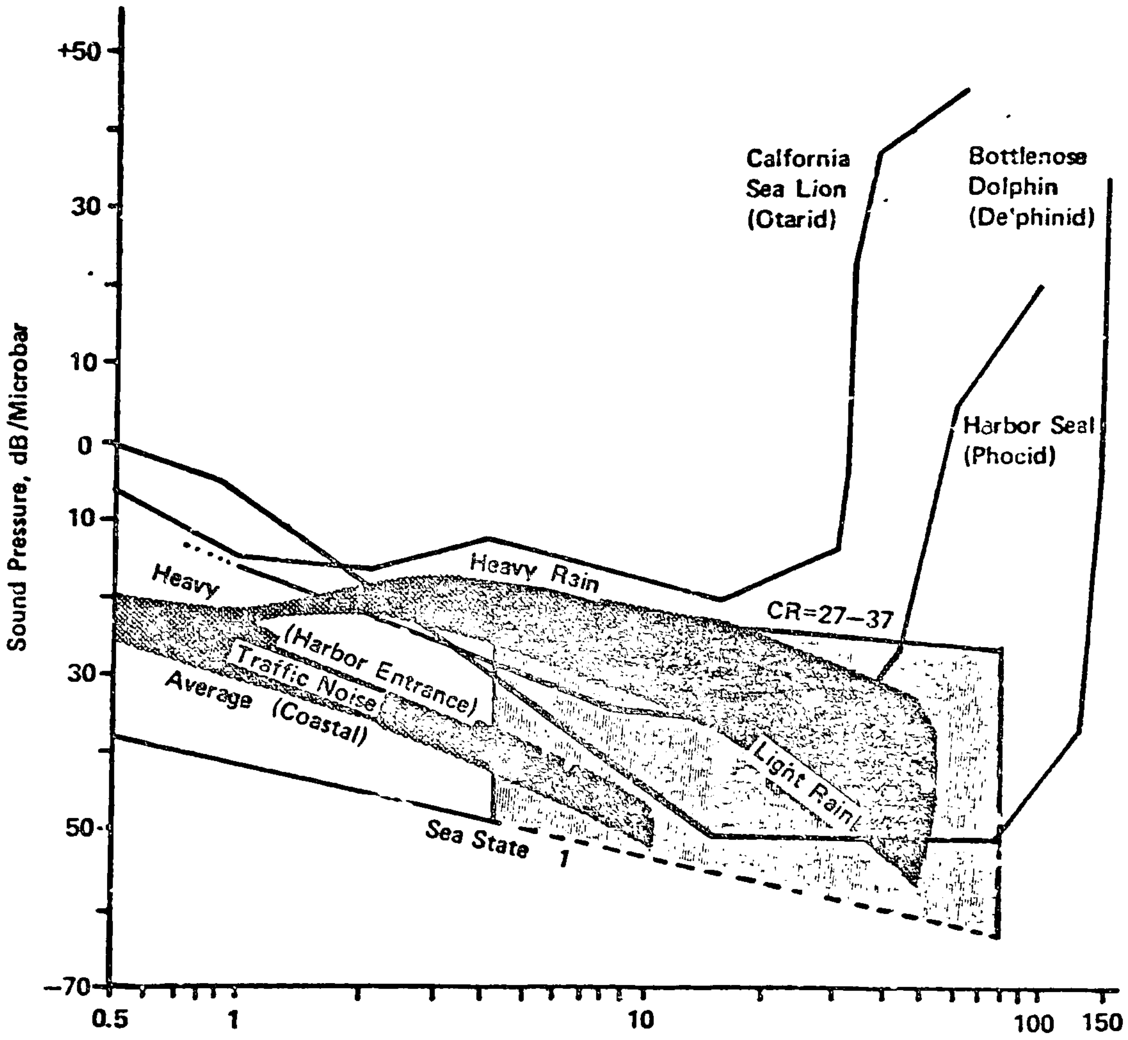


FIGURE 9. High frequency ambient noise and its probable masking effect on the hearing abilities of selected marine mammals whose peak sensitivities are found within that spectrum. Audiograms were redrawn from several authors. The hatched area is the region chosen to show the amount of masking that would extend above the arbitrarily chosen level of ambient noise (in spectrum level) with the critical ratios (CR) provided. (Myrberg, 1980)

**TABLE 5.** Estimated sound-detection distances under different ocean-noise conditions for the harbor seal, *Phoca vitulina*.

Selected audio-frequency, 9 KHz; audio-threshold: spectrum level noise ratio = 30 dB. Sound-source level (p-p) in dB/$\mu$bar re 1 m (e.g., conspecific) = +38 (Myrberg, 1980).

| | At Sea-State | |
|---|---|---|
| | 1 | 2 |
| Most sensitive threshold (decibels/$\mu$bar) | -22 | -15 |
| Estimated maximum detection distance (meters) | 1000 | 500 |

| | At Sea-State 1 | | | |
|---|---|---|---|---|
| | Traffic level | | Rain Level | |
| | Average | Heavy | Light | Heavy |
| Most sensitive threshold (decibels/$\mu$bar) | -19 | -14 | -3 | +9 |
| Estimated maximum detection distance (meters) | 750 | 425 | 120 | 30 |

their metabolic rate. Moen suggests that during this critical period, noisy snowmobiles and other disturbances may prevent successful energy retention, resulting in increased deer mortality. Such disturbances may also seriously affect species that hibernate.

The only physiological study of hibernating mammals is one concerning bats (Miline, et al., 1969). Histophysiological changes in the pineal glands and supraoptic nuclei of the brain were found after the bats were exposed to an electric bell rung twice daily (6 to 7 a.m. and 8 to 9 a.m.) for 7 days. Until more research is undertaken, the significance of these findings is unclear.

## BEHAVIORAL EFFECTS

Noise is most often considered an aversive stimulus, although some types of sounds actually attract animals. Large animals such as elk, bison, and cattle are sometimes attracted to trains and have created hazards by walking onto the tracks. Porpoises are drawn to boats so they can be pushed by the front wave. They are attracted from a distance by the noise of the propellers (Busnel, 1978). The acoustic characteristics (level, spectrum, duration, etc.) and type of noise source are obviously critical variables for behavioral reactions to noise. The noise sources in these studies on mammals are sonic booms, aircraft flyovers, electric power lines, vehicles, and construction sites near wildlife habitats. The presence of humans and/or machines can exaggerate or otherwise affect an animal's reaction to noise. In fact, it may be difficult to determine which affects wild animals more acutely--human presence or noise. These factors introduce confounding variables in noise effects research.

Studies on wild mammals include species such as house mice, rabbits, wild rats, bats, marine mammals, wolves, bear, and a number of hooved species (antelope, caribou, deer, wild sheep, etc). Startle or fright is the immediate behavioral reaction to transient, unexpected or unpleasant noise in all these mammals. Frightened mammals often run away or interrupt their activities. For example, reindeer seem to experience difficulties in herding, due to the hum of the power lines (Klein, 1971). If noise persists in a particular area, animals may leave their habitat and avoid it permanently. The physiological and ecological consequences could be serious to species survival, if the new habitat has inferior conditions. Kucera (1974) noted that avoidance behavior by mammals requires the expenditures of excess energy that is needed for survival. Avoidance behavior usually implies that an animal must find new food sources, watering holes, and nesting areas, all essential activities for survival requiring energy expenditure.

According to Kucera (1974), other mammalian behavioral reactions to noise include altered migration patterns, changes in the home range (the region where an animal usually moves), and the formation of aberrant behavior patterns between specific individuals, such as refusing to or not being able to mate.

Besides observations in the natural habitat, some studies investigate wild animals under laboratory conditions. Wild rats and mice were subjected to various noise frequencies (100 to 25,000 Hz) and sound pressure levels (60 to 140 decibels) by Sprock, et al. (1967). The effects of the noise ranged from decreased nesting close to the noise source to deaths at the highest intensities. Not surprisingly, recorded rat distress calls also decreased the time spent near the noise source by the animals.

In another study of this type, confined colonies of wild Norway rats and house mice were exposed to pulsed ultrasound provided by an ultrasonic generator for 76 and 81 days respectively (Greaves and Rowe, 1969). After exposure, the rodents displayed aversion to the sonic field and did not reenter the testing ground. The frequency, intensity, pulse duration, and length of time between pulses were not reported, although ultrasound is usually defined as sound in frequencies exceeding 20,000 Hz. Since rodents can detect very high frequencies of 1000 to 100,000 Hz (see Table 4), ultrasound as so defined is well within the hearing range of the rat.

Besides laboratory studies, observations can be made on mammals confined in zoos. The reactions of captive animals may be quite different from those of the same animals in their natural habitats. Cottereau (1978) stated that London zoo animals had no overt responses to high level sonic booms. Since sonic booms are often frightening to wild and domestic animals, it is not known why these zoo animals did not respond.

Most of the observations of wild mammals have been made in their natural habitats. Except during rainy weather, the ambient noise levels reported for wilderness areas on land are often quite low, from 20 to 40 A-weighted decibels (Luz and Smith, 1976; Soom, et al., 1972). Many of these data are from North American forests. Since the impact of noise varies from one species to another, the studies below are summarized by species. Some repetition is inevitable, since several investigators have observed more than one species at a time.

**Rabbits.** A novel but difficult method of observing wild animals is to attach radio transmitters to them and follow their movements, a method called telemetry. Such a study was done by Soom, et al. (1972) to observe the effects of snowmobile noise on the movement of seven wild rabbits. The researchers tried to separate the noise effects from the exhaust fumes, lights, the snowmobiles themselves, and other confounding variables. The animals had to be trapped and released after the transmitters were installed in collars so that handling added another factor to consider. The radio transmitters operated at a different frequency for each rabbit and transmitted over about half a mile. Signals from the rabbit transmitters were detected at two towers each with two antennas. Angular positions of the rabbits were determined using pointer positions on a protractor. Rabbit movement was studied for three nights before any snowmobile traffic had occurred, and then for six nights during snowmobile test runs. Observations occurred from 6 p.m. to 6 a.m. each night. Snowmobile noise was measured near where the rabbits moved at five different spots in the woodlot, so that the levels were lower than when snowmobile noise is measured close to the source. Ambient noise levels ranged from 20 decibels during quiet to 45 decibels due to cars. The 20 minute snowmobile runs were made three times hourly for 5 to 6 hours per night. The distance moved (in feet per hour) by the rabbits and the size of their home range were calculated as measures of activity. The results showed that snowmobile noise tended to increase rabbit movements and to increase their home range during the snowmobile runs. The home ranges decreased when snowmobiling ended, but did not return to the presnowmobiling level. Since only seven rabbits were observed for a very short period in a 14.5 acre woodlot, it is not known what the long term effects of snowmobile noise are on rabbits. Although the rabbits remained in their habitat, definite changes in movement were observed.

Another field study method was used by Busnel and Briot (unpublished) in the areas around several airports in France. Small mammals and raptors are periodically hunted in these areas to reduce the danger of collisions with aircraft. The investigators studied the hunting records kept by the airport administrators and scientists for any effects on the numbers of the various species. High noise levels of over 80 decibels, A-weighted, are common around airfields. Although some correlation was observed between a reduction in the population of hares and the opening of Roissy airport (where the traffic is very heavy), noise was not thought to be a major factor. No significant reduction in the population densities of either rabbits or hares was attributed to noise.

In another study (Crummett, 1970) rabbits were repelled by an acoustic signal produced by a commercially available noise production unit. No details regarding the duration of the acoustic signal were given. However, the alarm unit produces signals with frequencies of 2,000 to 4,000 Hz. The signals are amplitude and frequency modulated to maximize jamming efficiency relative to the particular species under observation. The noise unit is designed to minimize adaptation, as a warning or deterrent, and was reported to be quite effective.

**Bears.** Little information is available on the effects of noise on bears, except in connection with the environmental impact studies done for the proposed Mackenzie Gas Pipeline (across Alaska and Canada). A major source of noise during and after pipeline construction would be increased aircraft flyover (for surveillance) and construction equipment noise. Such noises may cause fright or confusion in these species. The noise may disturb bears during hibernation with a similar loss of thermal energy as mentioned above in regard to deer (Alaska Natural Gas Transportation System, 1975; Kucera, 1974).

McCourt, et al. (1974) observed that grizzly bears ceased their normal activities and ran away even when small airplanes flew over at 1000 feet, indicating a fright reaction. Other observers have noted a variety of reactions by grizzlies to aircraft, suggesting strong individual differences. Although there are very limited data on the effects of aircraft flyovers on grizzly bears, repeated flyovers may alter their home range, foraging patterns and breeding behavior. Although no data have been reported on the responses of polar bears to aircraft flyovers, this species is considered endangered. It has been recommeded that aircraft not fly lower than 2000 feet over either grizzlies or polar bears (Kucera, 1974).

**Wolf and Coyote.** Doll, et al. (1973) found that wolves were frightened by very low aircraft flyovers of 25 to 100 feet, but flyovers of between 200 and 1,000 feet only seemed to frighten 30 to 40 percent of the wolves. It has been reported by Klein (1973) and Mech (1970) that wolves can adapt to aircraft noise as long as they are not hunted from airborne vehicles.

The coyote was also discussed in a review of the environmental effects of high voltage power transmission lines (Ellis, et al., 1978). A coyote family was observed to be playing and feeding under a conductor with an A-weighted noise level of 63 decibels. The authors stated that power lines produce a relatively constant noise of the same volume that rarely changes abruptly. The noise produced may be predictable enough (and therefore non-threatening) to ground mammals, such as the coyote, to allow them to adapt.

Hoofed Mammals. The greatest number of noise studies was obtained on this group, which includes seven different species. Cottereau (1978) reported that deer near Eglin Air Force Base showed no response to high level sonic booms. Moen (1975) hypothesized that deer would be more susceptible to noise disturbance during the coldest and snowiest months (January through March). Since deer try to conserve energy by decreasing activity during this period, noise disturbance (such as snowmobiles) may cause an increase in activity and a dangerous energy loss.

Soom, et al. (1972) studied the effects of snowmobile noise on deer behavior in a 3000 acre swampy area of Wisconsin. The study focused on 140 acres. Radio transmitters were placed on collars on eight captured deer, who were then released. Six snowmobiles were operated from 1 to 4 hours each afternoon for 8 days during February and March, around the perimeter and through the center of the 140-acre tract, where four of the deer lived. No point in the tract was further than 1000 feet from a snowmobile path. The deer movements were monitored before, during and after the snowmobile runs. One of the deer left the area on the first day, but returned the next. The snowmobile runs increased deer movement, which may be due to fright reactions. An obvious difference between sonic booms and snowmobiles in the studies above is that with the latter the machine and the human operator have disturbing effects in addition to the noise.

Ellis, et al. (1978) reported that reindeer avoid noisy electric power line corridors, unlike the coyote observations above. Fear of the power line structure itself may contribute to the avoidance reaction. On the other hand, a herd of longhorn sheep was observed sleeping and feeding near a power line emitting noise at 53 decibels, A-weighted, and elk have been seen moving through an area with a noise level of 63 decibels, also generated by a power line. Steady, predictable A-weighted noise levels up to about 60 decibels are probably not disturbing to many mammals, after a period of desensitization. Most of the observations and measurements on power line noise have been made during fair weather, since rain produces dangerous surges of electric power and higher noise levels. No information is available on the effects of these higher power line noise levels on wildlife, nor of the effects of the electrochemical oxidants and electromagnetic radiation in combination with the noise.

A few studies of sheep were done in connection with environmental impact studies on the proposed arctic gas pipeline. Dall sheep, which are known to be very fearful animals, were frightened by the noise from a simulated gas compressor station (Kucera, 1974). The noise level was about 107 decibels 15 feet from the source. The sheep abandoned that part of their normal home range within a mile of the simulated compressor and exhibited altered behavior patterns during the noise stimulus. McCourt, et al. (1974) and Feist, et al. (1973) found that helicopter flyovers were even more disturbing to the sheep than the simulated gas compressor noise. Since Dall sheep are particularly susceptible to disturbance, noise may adversely affect this species.

Pronghorn antelope, unlike Dall sheep, were not disturbed by helicopter flyovers at 60 decibels, A-weighted. However, flyovers of 77 decibels produced strong fright reactions in which the antelope fled (Luz and Smith, 1976). The antelope lived in an area with an ambient noise of 36 to 40 decibels or less. Likewise, moose were frightened by fixed wing aircraft flying at 200 feet or lower (Kucera, 1974). Canadian musk ox, once considered an endangered species, seemed to be quite disturbed by snowmobiles and aircraft noise and were observed to flee or to display aggressive behavior such as butting contests in the summer (Kucera, 1974). Roseneau and Warbelow (1973) estimated that frequent helicopter flyovers may cause up to a 16 mile shift in their summer range. Nevertheless, there is some evidence that musk ox can adapt to aircraft noise. For example, Fletcher (unpublished) reported that little or no reaction to airplanes was observed in musk ox living near airfields. Again, some animals seem to adapt to noise that is predictable and unchanging.

The last hoofed mammal to be included in this section is the caribou, which has been the subject of a number of environmental impact studies. Caribou can tolerate blasting noise in winter if they have not been under hunting pressure, which would make them more nervous. Caribou also tend to be more easily disturbed when they are in rut or during the fly season (Jakimchuk, et al., 1974). Roughly 30,000 caribou were observed fleeing from a helicopter which flew over at 500 to 1,000 feet. McCourt, et al. (1974) found that caribou avoid gas compressor stations and may use less of their habitat within 1 1/2 miles of a station. Since caribou have historically been insulated from noisy human activities, care must be taken not to create too much stress in the herds. During rut, the animals' maternal or mating behavior could become abnormal (Kucera, 1974). Other vital behavior patterns could be jeopardized at other times. Caribou, like Dall sheep, are a fragile species that may be susceptible to noise effects.

**Bats.** Noise can produce avoidance reactions in bats. A high frequency sound (4000 to 15,000 Hz) produced by twelve adjustable dog whistles was used to drive 500 to 1000 bats from a nuclear power station (Hill, 1970). Since the bats were able to escape the noise, damaging effects were avoided.

**Whales.** Several types of whales are currently endangered. Thus, the adverse effects of noise on whales must be considered in the context of species survival. Cummings (1971) reported that underwater projections of recorded killer-whale sounds caused migrating gray whales to reverse their direction of movement. Similar recordings were used by Fish and Vania (1971) to prevent movement of white whales into an Alaskan river during the time that red salmon fingerlings were migrating to the ocean. Pure tone stimuli at 500 and 2,000 Hz and random noise in the band from 500 to 2,000 Hz were then projected with the same intensity and the same on-off times as the killer whale sounds in the gray whale study above. These sounds also kept the white whales from moving up the river. These studies have shown that some sounds can temporarily influence whale movement during migration. It is possible that serious consequences would result if whales are repeatedly disturbed by noise during migration. More research is needed on these effects before conclusions can be drawn.

## SUMMARY

Hearing studies in marine mammals have involved determining their auditory sensitivities, as well as describing the importance of hearing in finding food, mating, avoiding predators, and in distance reception. Potential masked thresholds are provided for several types of marine mammals (sea lions, dolphins, and seals) with respect to various ambient noise levels. Studies in small desert animals observed damage to the auditory system due to motorcycle noise, as well as temporary hearing loss in kangaroo rats exposed to recorded dune buggy noise. The nonauditory effects of noise reported in mammals include possible reduced energy conservation in white-tailed deer due to snowmobile noise and histophysiological changes in the brains of bats exposed to an electric bell.

Most noise studies in wild mammals have recorded behavioral reactions, some of which are as follows:

- Startle or fright reactions of many species to noise
- Avoidance behavior, such as reindeer avoiding power lines
- Temporary effects of recorded killer whale sounds and other acoustic stimuli on gray and white whale migration.

## BIRDS

### HEARING

Marler et al. (1973) studied noise-induced hearing loss and potential masking effects in male canaries. White noise at B-weighted levels of 95 to 100 decibels was broadcast for 40 or 200 days after hatching, and the vocalizations of birds raised in these conditions were compared to those of birds surgically deafened at birth. The 40-day noise exposure was found to produce about 20 decibels of permanent threshold shift (PTS) and the 200-day exposure about 50 to 60 decibels of PTS. In the first season, vocalization of canaries exposed for only 40 days was significantly better than that of birds exposed for 200 days, which performed as poorly as the surgically deafened group. However, in the second season of song development the 200-day exposure group performed not significantly differently from the 40-day group.

### MASKING

The possibility that excessive noise interferes with bird communication and acoustic signal detection has also been considered. Social birds live under noisy conditions produced by their own species. Adelie penguins, flamingos, ducks, and geese are able to communicate over the noise of the colonies with no apparent adverse effects; the same is true for jungle species. These species seem to be able to discriminate among sound stimuli, so that communication is not disrupted. Potash (in press) reported that when Japanese quail were isolated from their mates, they increased the frequency of their "separation calls" when ambient A-weighted noise levels were increased from 36 to 63 decibels. The increase in the frequency of the calls improved the probability of communication. Hence, masking may not be as severe in naturally noisy habitats, unless the noise greatly exceeds the ambient noise levels. Apparently, each bird species has a different tolerance for noise (Busnel, 1978). However, Thorpe (1969) identified potential ecological effects of masking in birds. He suggested that increased background noise may mask signals that influence such processes as spacing to obtain optimum population densities in an area, nesting and care of young, and detection of prey or escape from a predator.

## NONAUDITORY PHYSIOLOGICAL EFFECTS

Most of the studies on the effects of noise on birds concern bird behavior; few are on physiological effects. The immediate overt response to noise in birds, as in other animals, is startle. Startle responses involve some aspects of the stress reaction, affecting heart rate and other parameters discussed in the Appendix to this report. Thompson, et al. (1968a) telemetrically recorded the heart rate response of starlings to various meaningful sounds. Distress calls produced by physically restrained starlings produced high heart rate acceleration and slow habituation to the sounds. Escape calls of starlings subjected to avian predators also caused slight heart rate acceleration and habituation after two or three trials. Likewise, a human voice produced increased heart rate and required two or three exposures before habituation occurred. Feeding calls, however, produced the mildest reaction, in that a negligible heart rate acceleration occurred and habituation occurred after approximately one exposure. The starlings appeared to be able to discriminate among sound stimuli and react to each sound individually.

Thompson, et al. (1968b) also found that the normal heart rates of wild starlings were elevated during the day relative to night heart rate values. The birds studied were housed individually in acoustical chambers wherein natural day and night lighting regimes were simulated. Starling distress calls were used as an acoustical stimulus. Starlings are normally active during the day, and initial heart rate responses to 10 seconds of the auditory stimulus during the day were significantly different from baseline heart rate. Although the same stimulus produced an initial, slow increase of heart rate at night, the decrease to baseline was slower than during the day. When starlings were tested individually, the initial response was less dramatic and the decrease in heart rate to baseline faster than when the birds were tested in groups of five. Seemingly, a "flock effect" was operating, in that responses of individual starlings were influenced by those of the group (Fletcher, 1971).

Regarding reproduction, there is speculation about the effects of transmission line noise, since many birds nest in or near the towers, which can have A-weighted noise levels of over 60 decibels when it is raining. Lee and Griffith (1978) reported, in their review of the effects of power line noise, that 37-millisecond sound bursts of 80 decibel noise (at 100 to 8,000 Hz) for 2 hours increased Japanese quail egg hatching time by 10 percent. Effects on the hatchlings, if any, were not reported. More research is needed before the true effects of power lines on bird reproduction can be determined.

## BEHAVIORAL EFFECTS

The studies or observations on bird behavior can be divided into four types: (1) the use of noise to repel unwanted birds from a certain area; (2) the effects of aircraft flyovers, sonic booms and other environmental noises; (3) attraction of birds to noisy areas; (4) noise-induced changes in reproductive behavior.

Many of the studies on using noise to rid areas of avian pests involve starlings. Some of the most effective noises are high-intensity (not defined) recordings of the species' own distress calls (Langowski, et al., 1969; Messersmith, 1970; Thompson, et al., 1968a; Wight, 1971). However, the same investigators reported rapid habituation even to species-specific distress calls when presented continuously. For maximum effectiveness, intermittent presentation has been suggested. More specifically, the final report of a Committee on the Problem of Noise (1963) stated that in order to scare birds away, a noise level of approximately 85 dB decibels sound pressure level at the bird's ear was required. The noise used consisted of loud bangs and birds' distress calls. Birds habituated quickly to the noise and it was recommended that distress calls be used no more than 2 minutes every 20 to 30 minutes and only during the day.

The residents of Denver, Colorado used the distress call method successfully in dispersing flocks of starlings by playing records of starling distress calls for four evenings as the birds arrived at roosts. The recordings consisted of repeated cycles of 30 seconds of starling distress calls played for 12 minutes. Habituation of the birds to the records was not observed, although some of the residents played them continuously. At least half the population of an urban area must play the distress call recordings for effective dispersal of unwanted birds (Pearson, et al., 1967).

Habituation to distress call recordings was reported by Block (1966). The distress calls were used to disperse roosting starlings during three series of treatments in 1962. The number of starlings was reduced from 10,000 to a few hundred during the experiment; however, the roosts were subsequently reinfested by a majority of the starlings.

The second type of observation on noise related bird behavior includes sonic booms, other aircraft noise, and construction noise. Sonic booms have not been found to produce any acute effects except startle in birds (Cottereau, 1978). The responses of wild turkeys to both real and simulated sonic booms were observed by Lynch and Speake (1978). In their experiment, small radio transmitters were placed on 20 wild turkey hens. This enabled the researchers to locate and observe the reactions of the hens and their poults to the sonic booms which occurred during the nesting and rearing season. The turkeys stopped their activity during the booms, but resumed their normal behavior after a few seconds. No altered maternal behavior was observed in the turkey hens due to sonic booms. The investigators concluded that decreased productivity due to behavorial changes did not occur as a result of exposure to sonic booms.

Davis (1967) observed the reactions of some ravens in Wales to a sonic boom. When the boom occurred, three or four ravens that had been cruising in the area were rapidly joined by others. Within 5 minutes approximately 70 ravens were agitatedly circling; 30 minutes later about 30 ravens were still flying in the area. In another study, Shaw (1970) reported that adult condors were very sensitive to noise and abandoned their nests when disturbed by blasting, sonic booms or even traffic noise. The most deleterious effects attributed to sonic booms were recent mass hatching failures of sooty terns in Dry Tortugas, Florida, discussed by Bell (1970) and Henkin (1969). Following 50 years of breeding success, 99 percent of the terns' eggs failed to hatch in 1969. Extremely low-altitude supersonic flights over the area may have driven birds off their nests and damaged the uncovered eggs. Similarly, Graham (1969) reported observations of the destruction of pelican eggs by gulls when white pelicans were driven off their nests by sonic booms.

A U.S. Department of Interior report on the environmental impact of the Big Cypress Swamp Jetport (1969) discussed B-720 jet overflight noise at altitudes of 500 to 5,000 feet over two sites in the park. Observers reported that no birds were flushed and no disturbances observed. Noise levels ranged from sound pressure levels of 75 decibels (with aircraft at 3,000 feet) to

96.5 decibels (with aircraft at 500 feet). However, it was also reported that few birds were in the area at the time and wind effects interfered with proper sound level readings.

Lastly, it has been reported that fixed-wing aircraft flying at 5000 feet have caused Canadian geese a half mile away to be flushed. Yet aircraft as low as 50 to 100 feet rarely flushed nesting females near airstrips. On the other hand, helicopter overflights have apparently caused nesting geese to temporarily abandon their nests, leaving the eggs open to attack by such parasitic birds as jaegers and gulls (Jacobson, 1974). Flushing is a common avian fright response, which may involve a significant disruption of normal behavioral patterns.

As was discussed in the section on mammals, the effects of the noise of the proposed arctic gas pipeline construction on birds and other animals have been studied. In a personal communication to Jacobson (1974), Beebe stated that he had seen Peregrine falcons ignore construction noise, other than blasting, when it was not near their nests. Jacobson reported (1974), however, that construction noise had apparently caused six falcons to abandon their nests. Like flushing, desertion of nests could be a dangerous disruption of normal behavior, affecting survival.

Since gas compressor stations will be a permanent part of the proposed gas pipeline, the effects of their noise have been studied separately. Similar to the Canadian geese responses to aircraft, snow geese, in response to simulated compressor noise, deserted an area within 3 miles of the noise source (Gollop and Davis, 1974). The presence of this simulated compressor station noise resulted in significantly fewer flocks of geese circling and landing near decoys placed in the area. In general, the geese were observed avoiding these noisy areas altogether. Thus, it is suggested that the location of gas compressor stations near feeding and nesting areas may force the geese to expend additional energy as they detour around the affected area. The significance of this disruption deserves study.

The third area of behavioral study in birds involves the attraction of certain birds to noisy areas. Since birds and other animals living near airports are regularly exposed to high noise levels, a number of studies of such populations have been done. Large birds of prey (raptors) and migratory species are very prominent on airfields, such that hazardous collisions between birds and aircraft are often a problem. It is expected that birds would be more afraid of occasional aircraft flyovers in isolated and very quiet areas (Busnel and Briot, 1978), because of the stimulus rarity. The surprising finding of these studies is that many birds are in fact attracted to airport runways, largely because of the abundance of small mammals in these areas, such as the meadow vole near Toronto International Airport (Brooks, et al., 1976).

Power line towers are other noisy areas to which birds are attracted. These areas are often used by raptors as nesting sites. As with airport runways, there are usually few people around to disturb them. Transmission line noise is highest during wet or windy weather, however no significant effects on birds nesting on or near these towers have been observed, regardless of weather. Another reason for the attraction to power lines may be that power line noise serves as a navigational aid. Birds have been observed to use power lines as travel lanes, but the possibilities have not been subjected to scientific testing (Ellis, 1978; Lee and Griffith, 1978).

One report of noise adversely affecting reproductive behavior appeared in a conservation newsletter (Anon., 1978). Excessive noise near the Hialeah racetrack during the breeding season of nearby pink flamingos was reported to have interfered with the birds' mating behavior in 1977. The number of chicks produced was lowered as a result. The following year, the racetrack was closed during the March/April breeding season, but no report on the change in the number of flamingo chicks produced has been published yet.

## SUMMARY

Hearing is a very important sensory modality in birds. It allows birds to find mates, to locate other birds' territories, to detect warning calls from other birds, and to catch prey or to avoid predators. Birds, many of which have hearing sensitivities similar to those of humans, have been demonstrated to incur hearing loss due to B-weighted noise levels of 95 to 100 decibels. Reductions in hearing acuity have been shown to have adverse effects on vocal development in the canary (Marler, et al., 1973). Since vocalization is such an important function for so many songbirds, more research on hearing difficulties created by noise in birds in their natural habitats should be conducted. These effects on hearing would be equally adverse in birds of prey or in scavengers (seagulls, pigeons, buzzards), since these types of birds depend on hearing for survival.

Two nonauditory effects of noise reported in birds are changes in heart rate and egg-hatching times. Heart rates of starlings were accelerated by meaningful or disturbing sounds, such as the distress calls of other starlings or human voices. Egg-hatching times were increased in Japanese quail eggs exposed to 80 decibel sound bursts.

The observed behavioral effects of noise on birds include a number of fright reactions, altered mating behavior, and attraction to some noisy areas (apparently for reasons not related to noise exposure). The fright responses of birds may involve flushing, or the more serious desertion of nests, which may result in eggs not hatching. High noise levels during the breeding season of a colony of pink flamingos reportedly adversely affected the mating behavior, resulting in fewer chicks one year. Predatory birds are often attracted to noisy areas around airports or power lines. Although there are probably factors other than noise attracting the birds (such as fewer humans and more prey), there are no reports of harm to these birds by the noise.

# REPTILES

## HEARING

In reptiles, it has long been thought that chemoreception (the reception of chemical stimuli) and sight are much more important senses than hearing. Many reptiles cannot even produce sound (Lee and Griffith, 1978). However, certain desert reptiles are quite sensitive to low intensity sounds, especially in the spring and fall (Bondello, et al., 1979). Hearing seems to be an important sense for these reptiles.

The desert iguana, Dipsosaurus dorsalis, has hearing that is most sensitive in the 900 to 3000 Hz range. The adverse auditory effects of noise from offroad vehicles (ORVs) were investigated in this species by Bondello (1976) using a recording of motorcycle noise played at an A-weighted level of 114 decibels. Bondello subjected one group of 12 iguanas to this noise under laboratory conditions for 1 hour, another group of 12 for 10 hours, while a final group of 12 served as controls. The iguanas' hearing was then tested immediately after the noise exposure and again 7 days later. Hearing was evaluated by measuring the cochlear potential by means of an electrode implanted at the round window of the ear.

Hearing was found to be poorer in the test immediately following exposure, indicating a temporary threshold shift had occurred. Both exposure times, 1 and 10 hours, produced a reduction in hearing acuity that was measurable on day 7. A 10-hour exposure induced a threshold shift as high as 30 decibels at 1,000 Hz, which coincides with the animal's most sensitive frequency. The final results indicated that at 114 decibels, a "destructive dose" (where the recovery time exceeds 7 days) was less than 1 hour. It was observed that the normal operation of ORVs generates sound intensities greater than 114 decibels, with cumulative durations greater than 1 hour. Because ORV rallies, contests, and meets are held in areas where wildlife reside, the operation of such vehicles may pose a threat to some desert wildlife.

A more recent study by Bondello, et al. (1979) demonstrated hearing loss in seven lizards exposed in the laboratory to tape-recorded typical dune buggy sounds. The lizards were Uma scoparia (Mojave fringe-toed lizard), which live in or near eolian sand dunes. The noise dose was administered for 8 minutes, 30 seconds at an A-weighted sound level of 95 decibels (100 decibels sound pressure level). Exposure was intermittent with a 30-second duty cycle of 25 seconds on and 5 seconds off. The exposure level was representative of a dune buggy at 5 meters, but is not a maximum level, because dune buggy noise of 105 decibels sound pressure level at 50 meters has been recorded. The hearing loss was inferred from decreased amplitudes and increased latencies of averaged evoked responses (AER) of telencephalic EEGs made using implanted electrodes. The correct position for recording AER was physically verified after the animals were sacrificed. Because the animals were sacrificed immediately after the experiment, it was not possible to determine whether the lizards had experienced a permanent or temporary threshold shift. Hearing losses incurred by lizards in the wild were thought to be likely because of the observed tendency of ORVs to repeatedly traverse the same area, especially at such ORV "playgrounds" as Glamis, California. Moreover, intensive ORV activities in spring and summer coincide with the reproductive season of all three species of Uma, making secondary behavioral effects of noise also possible.

## AMPHIBIANS

### HEARING

As Table 4 shows, the range of hearing sensitivities of the bullfrog (Rana catesbeiana) is from under 10 to 3000 or 4000 Hz, with its maximum sensitivity at less than 1800 Hz (Lee and Griffith, 1978). Unlike many mammalian species (rodents, dogs) which are sensitive to frequencies much higher than humans can hear, the bullfrog has a much lower range of detectable frequencies.

Auditory sensitivity data have also been obtained for Couch's spadefoot toad (Scaphiopus couchi), which is the subject of the one noise effects study on amphibians (Bondello and Brattstrom, 1979b). This spadefoot toad has two areas of maximum sensitivity: a lower auditory frequency range of from 100 to

700 Hz, with its maximum sensitivity at 480 Hz, and an upper frequency range from 900 to 1500 Hz, with maximum sensitivity at 1400 Hz. The occurrence of upper and lower frequency ranges in this species is due to the presence of two sets of auditory nerve fibers which respond to different frequencies. Some other amphibians have three sets of auditory nerve fibers, corresponding to low, medium and high frequencies (Capranica and Moffett, 1975, as cited in Bondello and Brattstrom, 1979b). Such specialized development of the amphibian auditory system may indicate the importance of hearing to this group of vertebrates.

## BEHAVIORAL EFFECTS

In a recent laboratory study (Bondello and Brattstrom, 1979b), it is suggested that off-road vehicle (ORV) noise may have a negative impact on spadefoot toad (Scaphiopus couchi) populations because of its similarity to the sound of thunder. It has been established that spadefoot toads, found on the fringe of sand dune areas in the U. S. Southwest, can be induced by acoustical cues from ORV noise to emerge from their burrows during the wrong season, when there is insufficient water. Twenty toads were allowed to burrow in 10 centimeters of fine sand within a 15 gallon terrarium. Recorded motorcycle sounds of 95 decibels (A-weighted) were played for periods of 10, 20, and 30 minutes. The toads surfaced in response to the sound in the following numbers: from 1 to 7 after 10 minutes (3.3 average; 7 trials); from 4 to 11 after 20 minutes (5.7 average; 6 trials); and from 6 to 12 after 30 minutes (7.5 average; 4 trials). No toads surfaced during quiet control trials. The motorcycle sound evidently resembles the sound of thunderstorms, which are extremely important to spadefoot toad ecology, because breeding occurs in temporary rain puddles. Most of the toads did not reburrow after the end of the sound, which would increase the consequences of emerging at the wrong time, since their limited energy and water resources are severely depleted by the act of surfacing.

# FISH

Since many species of fish are of great practical importance, both economically and as part of our food supply, the effects of noise on fish should be given careful study. Although fish are not domestic animals per se, among those species raised for sport and food, there are similar considerations to those of the domestic mammals and birds.

## HEARING

The auditory system of fish and other aquatic animals is their most important distance receptor system, and it furnishes information on food, mates, predators, and other factors related to survival (Myrberg, 1980). Fish are extremely sensitive to low frequency sounds, and this sensitivity is measured using conditioning techniques (Cottereau, 1978). Hearing sensitivity data for several marine fishes are given in Figure 10 (Myrberg, 1980).

As the data in Figure 10 show, unlike the marine mammals, most marine fish are sensitive to frequencies below 2000 Hz. However, fish in the cypriniform group, which is composed of mostly freshwater species, such as minnows,

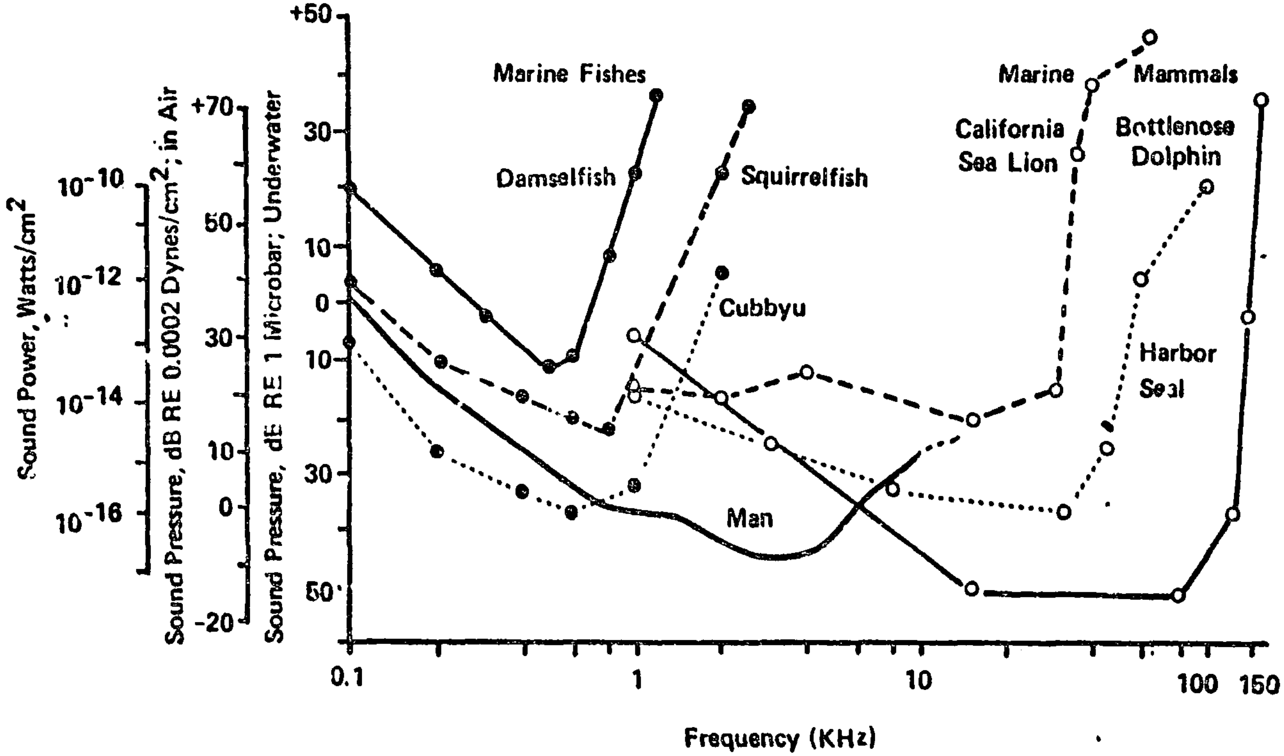


FIGURE 10. A comparision of hearing curves among selected marine fishes, marine mammals, and man. (Myrberg, 1980)

goldfish, and catfish, are able to detect frequencies from 5,000 to 10,000 Hz. Only a few marine species, such as herring, can detect sounds in this range.

Marine fish can be grouped according to their hearing sensitivities. The group whose peak sensitivity ranges from 75 to 300 Hz includes sharks, haddock, cod, pollock and toadfish. These fish are able to hear sounds from 10 to 500 Hz. This hearing range is useful for sharks, because the sounds produced by their prey are also in this range. The other fish in this group produce sounds in this range, so that the hearing sensitivity is important for intraspecific communication. The next group has a peak sensitivity range of from 400 to 800 Hz and includes damselfish, cubbyu, bonefish, blue-striped grunt, and squirrelfish. These fish can detect sounds from about 200 to 1000 Hz, and are the most numerous fish species inhabiting shallow water areas. Generally, related species from similar habitats have similar hearing sensitivities (Myrberg, 1980).

In general, hearing sensitivities seem to coincide with the acoustic frequencies of vocalizations. The toadfish is an exception to this principle. The toadfish mating call, or boatwhistle, has a fundamental frequency which varies seasonally from less than 150 to greater than 250 Hz (Fine, 1978). Auditory acuity in this species is mismatched with sound production in that the toadfish is more than 20 dB less sensitive at 200 Hz than it is at lower frequencies (40 to 90 Hz; Fine, 1981). According to Fine and Lenhardt (1980), this mismatch and other factors such as the short sound transmission distance (less than 5 or 6 meters in water about a meter deep) combine to make reception of the call a vulnerable process.

Although much is known about the hearing sensitivities of fish, very little is known about hearing loss in fish due to noise. Goldfish were found to experience temporary threshold shifts after 4 hours exposure to intense noise levels of +49 dB/μbar. Similar results were produced by lower noise levels in the lane snapper (cited by Myrberg, 1980). The potential effects of hearing loss are similar to the effects of masking, for which more studies are available. These studies are discussed in the next section on masking.

## MASKING

As with the marine mammals, fish may be highly susceptible to the masking of their auditory signals, which are very important for survival. Marine fish produce a variety of sounds, many of which are used for intraspecific communication, especially regarding reproductive behavior. Detection and localization of prey are other important uses of sound, such as by sharks. The varied sounds produced by members of one species of fish (the damselfish) define the courting males' territories. These sounds may also be used for attracting mates. Myrberg (1980) points out that sound reception, discrimination, and localization may be adversely affected by noise.

Popper and Fay (1973) state that the few studies which exist on masking in fish provide only fragmentary data. These experiments are very difficult to interpret, since the auditory system of fish is not fully understood. Moreover, masking may be more complex in fish than in terrestrial vertebrates because of the possible presence of multiple receptor systems.

Some of the potential masking effects of ambient noise are presented in Figures 11 and 12, including data on fish with peak hearing sensitivities of 75 to 300 Hz in Figure 11 and those with peak sensitivities of 400 to 800 Hz in Figure 12 (Myrberg, 1980).

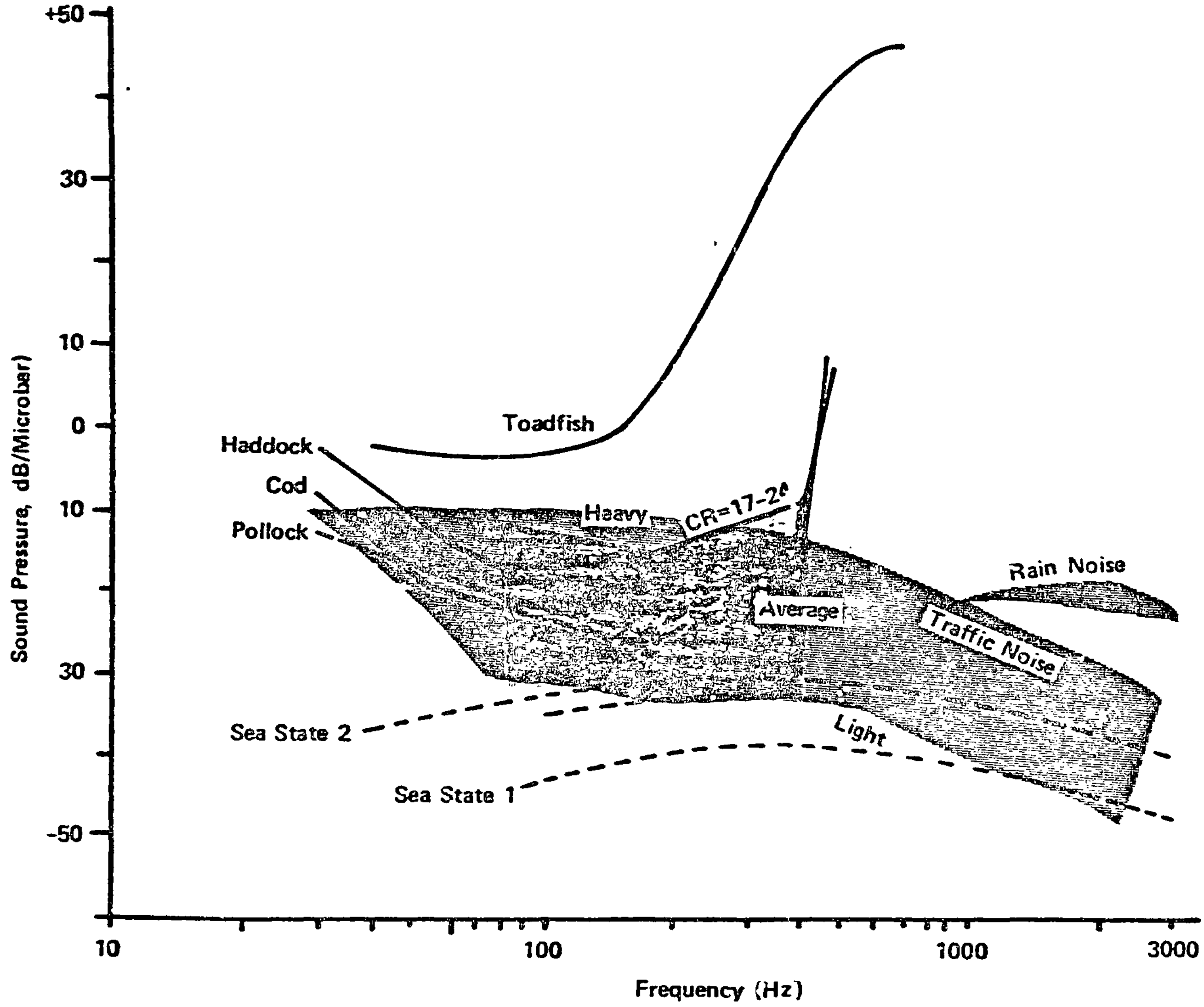


FIGURE 11. Low frequency ambient noise and its probable masking effect on the hearing abilities of selected marine fishes, whose peak sensitivities are found within that spectrum. The four audiograms shown were determined either totally, or partially, in the field. The hatched area is the region chosen to show the amount of masking that would occur above the arbitrarily chosen spectrum levels of sea state (≤ 2) and traffic noise (light) for those species possessing the critical ratios (CR) as given. (Myrberg, 1930)

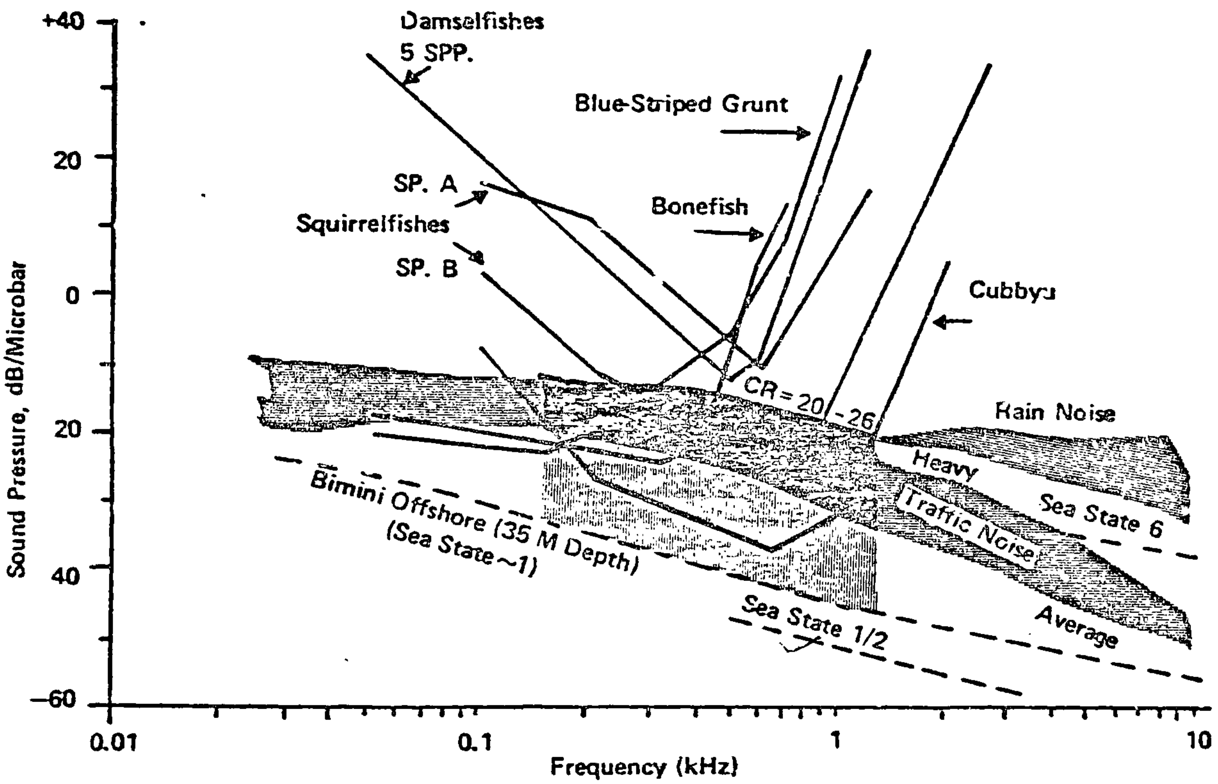


FIGURE 12. Low frequency ambient noise and its probable masking effect on the hearing abilities of selected marine fishes, whose peak sensitivities are found within that spectrum. The hatched area is the region chosen to show the amount of masking that would extend above the arbitrarily chosen level of ambient noise (in spectrum level). The ambient chosen was offshore the island of North Bimini, Bahamas where all the species reside. Audiograms were selected from various authors. (Myrberg, 1980)

Another way of assessing the effects of masking is to determine the effects of various ambient noise levels on the sound detection distance. Table 6 (from Myrberg, 1980) shows this for two different sea states and three different traffic levels, showing, in general, shorter detection distances for higher ambient levels. The sound source levels used are those of other members of the same species or those of the prey (in the lemon shark).

## NONAUDITORY PHYSIOLOGICAL EFFECTS

Some physiological changes have been noted in fish due to sonic booms. Sonic booms reportedly produce brief startle responses in fish, with some changes in heart rate. For example, Myrberg (1980) reported decreased heart rate (bradycardia) in response to sonic booms. Apparently, this is a common fish response to many sounds, such as ship noise.

Sonic booms have also been studied in relation to fish because of possible adverse effects on the eggs and young (fry or sprat). Some effects were studied in a number of species, including chinook salmon, rainbow trout, and steelhead trout, which are commonly raised in fish hatcheries. Normally reared trout and salmon eggs were exposed, 6 to 8 days after they were fertilized, to sonic booms ranging from 0.89 to 4.16 pounds per square foot (approximately 170 to 190 decibels). Exposure to the booms, at that stage of development, did not increase mortality rates. Similarly, 8-inch rainbow trout were exposed to a 1.90 to 2.44 pounds per square foot sonic boom (approximately 134 decibels) while in a 6-foot section of a rearing pond. Although the boom caused a "slight fright response" in the fish, no significant stress reactions were observed. In this case, stress was defined as a decrease in plasma osmolality or an increase in either the blood sugar (glucose) or blood cortisol levels (Rucker, 1973). Because the earliest blood sample in the test was not taken until 30 minutes after the sonic boom, some of the immediate noise effects may have been missed. More studies on stress reactions in fish are needed before these findings can be interpreted.

Another study on fish development (Myrberg, 1980) involved controlled tests of noise on two species of estuarine fish: Cyprinodon variegatus and Fundulus similis. Egg mortality, fry survival, and fry growth were compared in a noisy and quiet tank. Noise levels that were 40 to 50 decibels over the normal ambient noise of their habitats at low frequencies of 40 to 1000 Hz significantly reduced the viability of the eggs. Noise levels at 20 decibels over ambient noise however did not produce these lethal effects. No lethal effects were observed in the fry, but growth rates were significantly reduced. The results are summarized in Figure 13.

Thus, adverse physiological effects seem to pose a threat to fish mainly in the immature stages, affecting hatchability, growth rate, and development. However, the noise levels necessary to produce these effects may not occur in the marine environment with great frequency. Except for some fright or startle responses, sonic booms do not seem to pose a great threat to adult fish (Cottereau, 1978).

## BEHAVIORAL EFFECTS

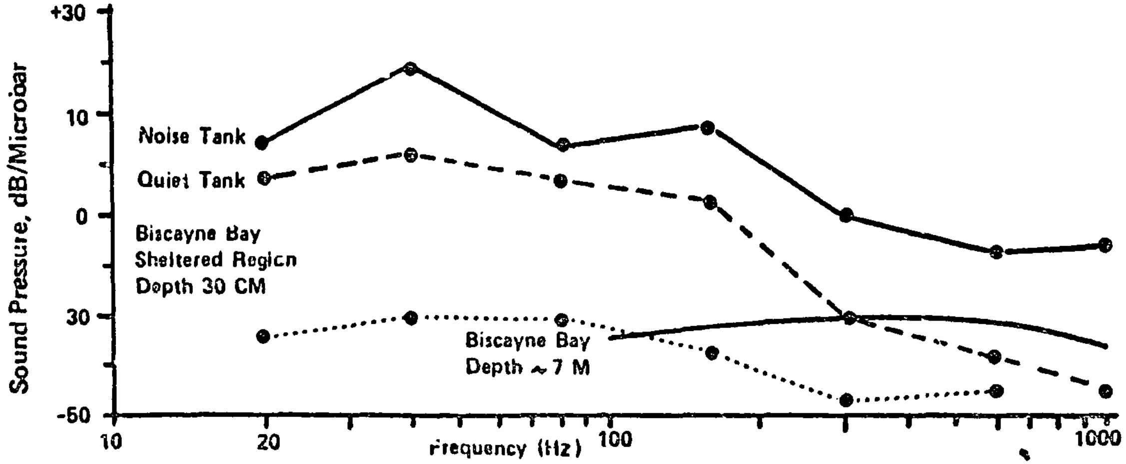
Some fish are attracted to and seem to be unharmed by noise. For example, sharks are attracted to the noise of ships when searching for food. In Venice,

## TABLE 6. Estimated sound-detection-distances under different ocean-noise conditions for selected species of marine fishes.

Conspecific source levels used in all calculations, except for those involving the lemon shark; audio frequencies selected from regions of peak energy for the respective sound sources (Myrberg, 1980).

| Species | Sound-Source Level (dB/μbar re 1 m) | Selected Audio-Frequency (Hz) | Audio Threshold; Spectrum Level Noise Ratio (dB) | At Sea State | Most Sensitive Audio Threshold (dB/μbar) | Estimated Maximum Detection Distance (Meters) | At Traffic Level (Sea State 1) | Most Sensitive Audio Threshold (dB/μbar) | Estimated Maximum Detection Distance (Meters) |
|---|---|---|---|---|---|---|---|---|---|
| *Eupomacentrus partitus* | + 7 | 500 | 23* | 1 | -12 | 9 | Light | -12 | 9.0 |
| Bicolor damselfish | | | | 2 | - 7 | 5 | Average | - 3 | 3.5 |
| | | | | | | | Heavy | + 6 | 1.0 |
| *Holocentrus rufus* | +13 | 600 | 23 | 1 | -16 | 30 | Light | -13 | 20.0 |
| Longspine squirrelfish | | | | 2 | - 8 | 12 | Average | - 4 | 7.5 |
| | | | | | | | Heavy | + 5 | 1.5 |
| *Opsanus tau* | +35 | 100 | 17* | 1 | - 2 | 75 | Light | - 2 | 75.0 |
| Toadfish | | | | 2 | - 2 | 75 | Average | - 2 | 75.0 |
| | | | | | | | Heavy | + 7 | 30.0 |
| *Negaprion brevirostris* | +30* | 300 | 20 | 1 | -13 | 150 | Light | -12 | 130.0 |
| Lemon shark | | | | 2 | -10 | 105 | Average | - 3 | 50.0 |
| | | | | | | | Heavy | + 6 | 20.0 |

* Assumes values as stated in Myrberg (1980).



| Species | | Egg Mortality | Fry Survival 24 Hrs. | Fry Survival Post 24 Hrs. | | Fry Length | Fry Weight |
|---|---|---|---|---|---|---|---|
| Cyprinodon Variegatus | Noise Tank | – | – | – | → 12 Days | – | – |
| | | | Significant Difference | | Post-Hatch → | Significant Difference | |
| | Quiet Tank | + | + | + | | + | + |
| Fundulus Similis | Noise Tank | | | | 15 Days | | |
| | Quiet Tank | No Significant Difference | | | → Post-Hatch → | Significant Difference | |

FIGURE 13. Effects of sustained noise on egg mortality and fry survival and growth in two species of estuarine fishes (Cyprinodon variegatus and Fundulus similis). Ambient noise portrayed in spectrum levels. (Myrberg, 1980)

where there is a high level of motorboat traffic, no behavioral effects have been observed on the fish population. It is not known whether the fish in this area are deaf (Busnel, 1978), nor has the distribution of these fish been surveyed to determine whether certain species have abandoned the noisy waters. Fishing vessel noise, especially sudden changes in noise levels, can frighten schooling fish. Such fish were observed to change direction and to dive. Low frequency noise is usually the most frightening to fish (FAO Fisheries, 1970).

Malar and Kleerekoper (1968) analyzed locomotor patterns of individual goldfish before and after exposure to a 2,000 Hz sound at varying intensities 30 centimeters from the source. Locomotor patterns of the fish were significantly affected above a sound pressure of 2.0 dynes per square centimeter (a sound pressure level of 80 decibels).

Fine and Lenhardt (1980), in studying the underwater transmission properties of vocalizations of the oyster toadfish (Opsanus tau), have noted the particular susceptibility of vocal behavior to disturbance by noise. The male toadfish is likely to cease its mating call, or boatwhistle, when exposed to underwater noise. The authors suggest that noise may be capable of disrupting courtship in the toadfish and in other fishes of more commercial value. They further suggest that the suppression of calling behavior by noise indicates that potential to cause deleterious biological effects, and should be investigated in freshwater and nearshore marine systems.

## SUMMARY

Hearing is one of the most important senses in fish. It is used as a distance receptor system, to find prey or avoid predators, to locate mates, to define territories, and in a variety of communications both between and within species. Most marine fish are sensitive to frequencies below 2000 Hz, the peak areas of sensitivity being from 400 to 800 Hz in the cod and haddock and from 75 to 300 Hz in the lemon shark. An exception to this trend is the herring, which can detect frequencies from 5,000 to 10,000 Hz. Many more freshwater fish, such as minnows, catfish, and goldfish, are able to detect these high-frequency sounds. If peak auditory sensitivity is mismatched with the acoustic frequency of vocalizations, as in the oyster toadfish, communications may be particularly susceptible to disruption.

Temporary threshold shift (TTS) due to laboratory exposure to high noise levels has been reported in the goldfish and the lane snapper. Reported non-auditory physiological effects include decreased heart rate in response to sonic booms (a typical fish response to sound), slight startle reactions to sonic booms, significant reductions in growth rate of fry, and reduced egg viability in fish raised in tanks with noise levels 40 to 50 decibels over their usual ambient noise levels. Noise seems to be more capable of physiological harm to eggs and fry than to adults. Changes in movement patterns in goldfish due to various noise levels have been noted, and the male toadfish has been found to cease its mating call when exposed to underwater noise.

On the question of masking effects, Myrberg (1980) stated that fish are vulnerable to these effects due to the importance of sounds in the marine environment. Moreover, the ambient noise levels in the sea (which can be quite noisy due to shrimp, bad weather, and ship traffic) may degrade the communication abilities of fish. Sound detection distances were estimated to be considerably reduced due to heavier ship traffic and waves. Interruption of intra- and interspecies communication in fish has the potential of adversely affecting their reproductive behavior patterns, detection of prey, and a variety of other factors necessary for survival.

## INSECTS

Since many of the hundreds of thousands of insect species are considered pests, some of the noise effects literature emphasizes the use of noise as an aversive stimulus to repel or to kill insects. Nevertheless, all insects are beneficial to some extent, in that they serve as food for other animals. Many species are essential because they eat other insects (ladybugs, praying mantis, and dragonflies), because of their role in pollination (honeybees), or are desirable because of their great beauty (butterflies, scarab beetles). Thus, human efforts to eradicate or limit the more harmful insects must not be so overzealous that they kill off the beneficial species.

### HEARING

As Table 4 shows, insects such as some of the moths can detect frequencies from 20,000 Hz to over 200,000 Hz, whereas the mosquito cannot detect sound over 550 Hz. The great variation in hearing acuity among the seven insect species listed in the table (out of over one million species) indicates that generalizations about the effects of noise on this large group of invertebrates are not feasible. No studies on hearing damage due to noise in insects are available.

### NONAUDITORY PHYSIOLOGICAL EFFECTS

The majority of studies on the effects of noise on insect physiology seem to be related to reproduction and development. The effects of noise on larval growth might be used in controlling harmful insect populations. Two investigations involved exposing Indian-meal moth larvae to sound in order to interrupt development. The number of emerging adult Indian-meal moths was reduced by 75 percent, after the larvae were exposed to 120 to 2000 Hz sound (sound pressure levels unreported) for 4 days (Kirkpatrick and Harein, 1965). No such effects were produced in a similar study by Lindgren (1969), using a variety of noise frequencies and intensities on Indian-meal moths and flour beetles. The following pure tones were used: 70 Hz at 110 decibels, 200 Hz at 113 decibels, 1,700 Hz at 134 decibels, 2,000 Hz at 120 decibels, 10,000 Hz at 90 decibels, 20,000 Hz at 71 decibels, and 40,000 Hz with sound pressure level not reported. Variable frequencies of 180 to 2,000 Hz at 90 to 105 decibels and 180 to 2,000 Hz at 90 to 102 decibels were also used. Insects were exposed during the latter part of the pupal stage and for 2 to 4 weeks as unmated and/or mated adults. Very little, if any, effect was noted, with the possible exception of mated flour beetles exposed continuously to 40,000 Hz. Even though large numbers of insects were used in many replications, effects of sound exposure were difficult to demonstrate, because of variability in egg production. The conflict between the data of Kirkpatrick and Harein (1965) and Lindgren (1969) possibly can be explained by stimulation at different stages of the insects' life cycles, as well as by differences in the sound itself.

A series of studies on the effects of high level noise on the various stages of the flour moth were described by R.G. Busnel (1978). In these experiments, all developmental stages (egg, larva, pupa, and adult) were exposed to noise, in order to ascertain whether any particular stage was more susceptible than the others. The insects were bombarded with sounds of differing spectral characteristics as high as 180 decibels sound pressure level for various lengths of time. Using the selected noise spectra, levels, and durations, Busnel found that noise was an ineffective method for deinsectization. Moreover, it would be an impractical method due to the energy costs alone. The same conclusion was reached in similar studies by Andrieu et al. (1978), in which a moth (*Ephestia kuhniella*) and a beetle (*Tribolium confusum*) that infest flour were exposed to sounds at various developmental stages. At 180 decibels exposure from a random noise generator, the plastic box housing the adult insects was shattered, but the insects were still alive. The noise caused some damage to *Ephestia*, including broken wings and loss of scales. Behavior and motor activity of both adults and larvae were normal.

Besides effects on development, lifespan and egg production in adults have been investigated. Cutkomp (1969) reported that a 72-hour exposure to a pulsed sound having a frequency of 50,000 Hz, with 25 pulses per second at 65 decibels, reduced longevity from 20 to 10 days in corn earworm moths and Mediterranean flour moths. The sound was an aversive stimulus in that the insects were observed to move away from the sound source. In addition to longevity effects, the mean number of eggs per female was reduced 59 percent in the treated relative to the untreated group.

Although many of the insects studied were not very susceptible to high intensity noise, some species may in fact be more highly sensitive, as indicated in the longevity studies by Cutkomp (1969). Unless further research is conducted, the potential utility of exposure to noise in increasing the success of agriculture and reforestation efforts will continue to be unknown. Since insect damage to farm crops can have an extremely negative impact on the farm economy, research into the effects of noise on genetic or developmental transformations might be useful in alleviating future insect damage. The reduction of egg production due to noise exposure is another area for further study in insect management. Research on the physiological effects of noise on beneficial insects should also be undertaken in order to avoid population reductions of the useful species.

## BEHAVIORAL EFFECTS

Certain insects have been observed to be attracted to various sounds. Mosquitoes in swarms have been attracted by engine noise, and a mechanical piano reportedly attracted large numbers of mole crickets. The insects seem to be attracted to these sounds because the frequencies mimicked the females' mating signals (Busnel, 1978). Male midges were attracted to frequencies of 125 Hz at 13 to 18 decibels above the ambient noise level. The swarms of midges circled in an agitated manner around the sound source (Frings and Frings, 1959).

The effects of pure tones on locusts were described by Shulov (1969). Although tones of 4,000 Hz at 80 decibels sound pressure level had little effect on feeding behavior, tones of 1,000, 4,000 and 10,000 Hz elicited a flying response in more than two out of three trials.

The opposite effect, cessation of movement, has been observed in honeybees in response to certain sounds. Frings and Little (1957) reported that frequencies between 300 and 1,000 Hz with levels ranging from 107 to 119 decibels sound pressure level produced cessation of movement for up to 20 minutes. No habituation was observed after 2 months. Experiments by Little (1959) demonstrated that stimulation with sounds having frequencies from 200 to 2,000 Hz produced cessation of movement in honeybees. Vibration of antennae did not produce the effect, but vibration on any of the three pairs of legs produced the "freezing response." Cessation of movement was also noted in the Indian-meal moth in response to loudspeakers, bells, and whistles (Tsao, 1969). In addition, there was evidence of sex-related differences in the range of 2,000 to 40,000 Hz although the details were not specified.

Further studies on honeybees were in progress when reported by Lee and Griffith (1978). Honeybee colonies placed directly under an 1100/1200 kilovolt power transmission line noise source were being compared to colonies placed farther away. The A-weighted sound levels 15 meters from the power line were about 52 decibels. Since ambient noise levels in secluded areas can be quite low (20 to 30 decibels or less), a noise level of 52 decibels may be significant in comparison to the background. No behavioral effects on honeybees had been observed since the study began in 1977. Other parameters being considered were honey and wax production, mortality, swarming tendencies, and foraging. These beneficial insects are being used as indicator species to study the effects of noise on other insects.

## SUMMARY

Although the effects of noise on relatively few insect species have been studied, certain insects seem to be significantly influenced by sound. Apparently some insect species are susceptible to effects on life span, reproductive capacity, and behavior.

# SECTION IV. SUMMARY AND SUGGESTIONS FOR RESEARCH

## SUMMARY

Concluding statements in a report of this length and multitude of topics should be able to provide concise answers to some of the questions we have on the effects of noise on wildlife. As in most other research areas, simple answers are rarely available. It is especially difficult to predict the effects of noise in natural animal habitats. It is clear that any adverse effects may potentially have ecological consequences regarding animal populations, predator-prey relationships, intra- and interspecies behavior patterns, habitat preservation, and the food chain.

Three major areas of speculation remain with respect to noise effects on animals: 1) the effects of long term exposure to moderate or intermittent noise; 2) the probability that wild animals experience the same adverse physiological effects of noise as laboratory (and some domestic) animals; 3) the ecological consequences of adverse physiological changes, masking, and altered behavioral patterns.

As stated earlier, noise effects on animals in the laboratory have been documented better than in either domestic or wild animals. Of the four types of noise effects examined--hearing loss, masking, nonauditory physiological, and behavioral--the most conclusive evidence has been collected on damage to the auditory system. The major effects of noise on all three animal groups will be summarized by the type of effect.

## HEARING

The auditory sensitivities of animals are highly variable from one species to another as is evident from Table 4. Many animals can detect much higher frequencies than humans. One notable exception to this trend is that many marine fish are most sensitive to low frequency sounds. Auditory sensitivities in the species of interest should be taken into account in the measurement and assessment of noise exposures. For example, the A-weighting system is based on human audition, and is not necessarily applicable to other species. Another variable to consider in hearing effects across species is the relative importance of this sense for survival in each species. For example, hearing is very important to marine mammals and fish. The marine invertebrates such as shrimp and sea urchins produce a number of sounds; however the importance of hearing to these invertebrates has not been considered (Myrberg, 1980).

Observations on pathological changes in the auditory system due to noise have been made primarily in laboratory animals, including guinea pigs, mice, and chinchillas (which are also raised domestically). Anatomic changes in the ear include the destruction of the sensory hair cells in the organ of Corti, histologic changes in the cochlea (the major hearing structure), and electrophysiological changes in the form of decreased amplitude of the cochlear microphonic potentials, indicating reduced sensitivity to sound. Blood clots and bleeding in the inner ear have also been observed. Temporary threshold shifts (TTS) due to noise have been demonstrated and have been correlated with some of the electrophysiological changes.

Auditory changes representative of hearing damage have been demonstrated in canaries (due to 95 to 100 decibel tone bursts) and some small wild mammals, but very little in most wild and domestic animals. The desert iguana was shown to experience a TTS immediately after exposure to motorcycle noise at an A-weighted level of 114 decibels.

## MASKING

The potential consequences of interference with communication and signal detection are similar to those of hearing damage, except that, in practical terms, masking lasts only as long as the noise is present. There is much room for speculation about masking. Although masking is a demonstrated effect of noise, the degree of its occurrence and its potential secondary effects on life functions in natural habitats remain undetermined.

No masking effects studies were located on laboratory or domestic animals, reptiles, amphibians, or insects. Masking effects have been considered in wild mammals, wild birds, and in fish. Such animals use auditory signals for finding other members of their species (offspring, mates, etc), for locating prey or avoiding predators, for defining territory, for orientation, and in migration. Marine animals use sounds for distance reception as well as for the aforementioned reasons. Since auditory signals are used for behavior necessary for individual survival, any inhibition of normal behavioral patterns due to masking may affect survival. The potential ecological consequences of masking are still hypothetical, since no proof of these consequences exists.

One of the mammalian studies on masking reports that bats seem to be able to overcome masking by reorienting so that the signal and noise are from different directions (Griffin, et al., 1963). Myrberg (1980) has given consideration to masking effects in the marine mammals, such as dolphins, seals, and sea lions, as well as in fish. He has shown the likelihood that masking occurs by comparing ambient noise levels and the hearing abilities of the marine mammals and fish.

## NONAUDITORY PHYSIOLOGICAL EFFECTS

There are many complex effects on animal physiology produced by noise, as summarized and displayed in Table 7. The reader should also refer to the figures showing neuroendocrine pathways and stress physiology in the Appendix. Table 7 shows two things: (1) where the gaps are in noise research on animals; and (2) that the studies confirm that many of the physiological reactions to stress may occur in animals exposed to high noise levels. The major gaps in research on the nonauditory effects of noise are studies on wild animals of all types. Another neglected area is that of moderate chronic noise exposure. Almost all of the data reported here are the result of short term studies with very high noise levels (over 100 decibels).

## BEHAVIORAL EFFECTS

The only animals for which no behavioral studies on noise have been located are the reptiles. Many of the behavioral effects recorded for many

## TABLE 7. Nonauditory Effects of Noise

| Laboratory Animals | Domestic Animals | Wildlife |
|---|---|---|
| Biochemical Parameters: | | |
| Increased blood sugar<br>pyruvic acid<br>LDH (lactic dehydrogenase)<br>cholesterol<br>free fatty acids<br>triglycerides | No data | No effect on blood sugar in fish (no data on other animals or other parameters) |
| Decreased glutathione<br>eosinophils | | |
| Urinary Parameters: | | |
| Increased catecholamines (epinephrine & norepinephrine) | No data | No data on urinary parameters |
| No data (in this report) | Increased creatinine | |
| No data (in this report) | Increased urine output | |
| Neuroendocrine System: | | |
| Increased cortisol<br>aldosterone<br>(adrenocorticoids) | Increased cortisol<br>aldosterone<br>(adrenocorticoids) | Increased adrenocorticoids in hoofed animals. No effect in fish |
| Enlarged pituitary and adrenals | No data | Altered brain histology in bats |
| Increased acetylcholine activity<br>brain ascorbic acid<br>ADH (antidiuretic hormone)<br>oxytocin | No data | No data |
| Cardiovascular System: | | |
| Increased blood pressure | No data | No data |
| Increased heart rate | Increased heart rate | Increased heart rate in birds<br>Decreased heart rate in fish |
| Increase aortic atherosclerosis | No data | No data |

**TABLE 7. (cont). Nonauditory Effects of Noise**

| Laboratory Animals | Domestic Animals | Wildlife |
|---|---|---|
| Metabolic Factors: | | |
| Lung hemorrhages | Increased respiration rate | No data |
| No data | Increased digestibility and feed utilization | No data |
| Decreased body weight (Chronic noise) | Decreased food intake<br>Increased body weight in lambs (at 75 dB, but not at 100 dB) | Decreased body weight in hoofed animals |
| No data | No data | May interfere with energy conservation in deer |
| Not applicable | Adverse effects on meat quality | No data |
| Reproduction: | | |
| No data | Decreased milk production in cows | No data |
| Ovarian changes | Ovarian changes | No data |
| Testicular changes | No data | No data |
| No data | Altered gonadotropin levels in lambs | No data |
| Persistent estrus | No data | No data |
| Altered fertility | Altered fertility | No data |
| Lower weight gain of offspring | No data | Lower birth weight & growth of fry in fish |
| Altered Intervals between litters | Larger litters in mink exposed to sonic booms | No data |
| Increased resorptions malformations | No adverse effects reported | Increased resorptions & miscarriages in hoofed mammals |
| Not applicable | Increased hatchability or no effect in poultry | Lethal to some insect larvae but no effect on others. Decreased hatchability in quail |
| Other: | | |
| Lowered resistance to disease | No data | Lowered resistance to disease in hoofed mammals |
| Not applicable | Not applicable | Broken wings and scale loss in some insects (extreme noise levels) |

different species can be grouped into the following categories, which are not mutually exclusive:

1. Fright, startle or orienting response
2. Abnormal behavior patterns
    - aggression
    - cessation of normal activities (grooming, eating)
    - cessation of movement
    - altered reproductive behavior
3. Weakened reflexes
4. Learning decrements
5. Avoidance (may involve abandonment of the habitat, change in the home range, altered migration patterns)
6. No response, habituation, or adaptation
7. Attraction to the noise or the noisy area

The altered behavior of caged animals (laboratory or zoo animals) is confounded by the fact that they cannot escape noise. Domestic animals may also be unable to escape a frightening noise. Fright responses, abnormal behavior, decreased learning, and weaker reflexes have been observed in laboratory animals due to noise. Domestic animals, such as swine, sheep, and cattle, seem to be able to adapt to certain noise levels of 100 to 120 decibels (Bond, et al., 1963; Harbers, et al., 1975). Poultry seem to be especially fearful of loud noises, such as sonic booms. Maternal behavior in hens (brooding) was disrupted by aircraft noise (greater than 120 decibels), such that fewer eggs were hatched (Stadelman, 1958a).

The study of the behavioral effects of noise in wild animals may also be confounded by human presence, since many wild animals are afraid of humans. Fright reactions in many forms are almost universally observed in animals due to transient, unexpected noise. The tendency of some animals to avoid the area near a noise source may lead to adverse behavioral changes, such as abandoning the habitat. Avoidance behavior has been observed in geese, caribou, Dall sheep, reindeer, rabbits, and deer (Ellis, et al., 1978; Gollop and Davis, 1974; McCourt, et al., 1974; Soom, et al., 1972). Another type of avoidance behavior, altered migration patterns, has been observed in whales in response to killer whale sounds (Cummings, 1971; Fish and Vania, 1971). Both flying responses and freezing of movement have been observed in honeybees, although the significance of these effects has not been determined (Frings and Little, 1957).

Altered reproductive behavior due to noise is a major area of concern, due to the possible effects on species survival. One reported example is that fewer pink flamingo chicks were born due to the high noise levels of the Hialeah race-track in 1977 (Anon., 1978). Underwater noise was found to inhibit the mating call of the male oyster toadfish (Fine and Lenhardt, 1980). No adverse effects on these activities were reported in mammals or insects.

Besides fright and avoidance reactions, some animals are attracted to noisy areas. Birds of prey and small mammals are attracted to airport runways, possibly due to the availability of food. Insects and fish have been reported to be attracted to various sounds. Less noise research has been done on behavior of fish and insects than of mammals and birds.

## SUGGESTIONS FOR RESEARCH

Due to the vast number of animal species, priorities must be set up for studying both wild and domestic groups. Animals on which we depend directly for food (including many aquatic species) should be a prime area for research, since definite physiological and behavioral reactions due to noise have already been observed. The study of stress-induced color changes in meat (and other changes) is one area that should be explored, because of the potential economic value. Studies on milk production and egg hatchability affected by noise have yielded conflicting results in the past, and more studies should be done to resolve these conflicts.

Other priority animals should be endangered species and any species that seem to be adversely affected by environmental noise. One might also add to these two groups the wilderness species, such as those covered in the arctic pipeline studies. Even though many of these species are not in immediate danger, caribou and many other wilderness animals are considered to be in somewhat tenuous positions. Since ecological relationships are so important, it is of high priority to study certain geographic areas as a whole (as in the pipeline studies), considering multiple species and their interrelationships. Areas chosen for such study would be those for which noise is likely to be a problem.

Once species and geographic priorities for study are identified, the research plan should be carefully considered. A combination of field and laboratory studies will probably produce the best results. Long term studies of moderate noise exposure are badly needed. Bender (1977) suggests such a combination research effort, as summarized in Figure 14.

In addition to the studies of the adverse effects of noise, much more research is needed on the hearing sensitivities of various wildlife species. Better methodologies for studying noise effects also need to be devised, in regard to field study, signal detection and masking, and hearing sensitivity. The study of noise as a stressor should be continued, with more emphasis being placed on the interaction of noise with other stressors, such as crowding, toxic substances, or weather conditions. The nonauditory effects of noise on wildlife have received very little attention.

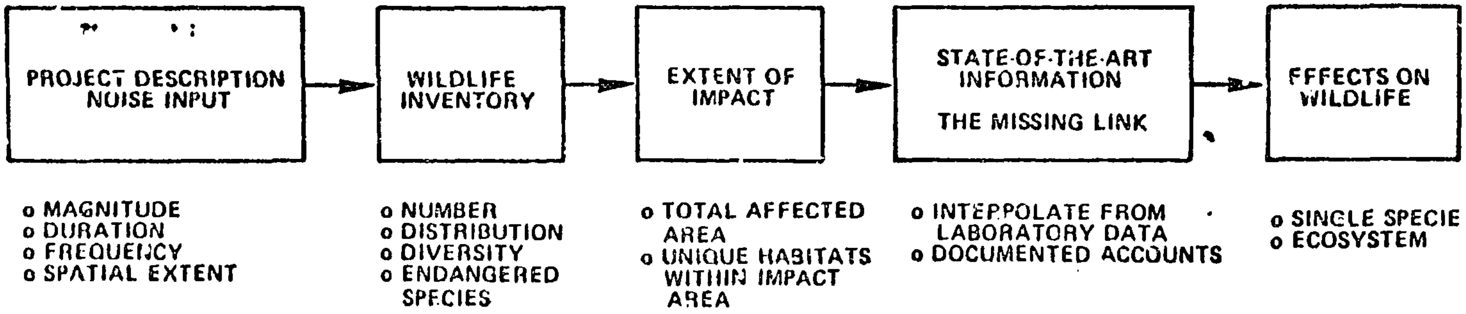


FIGURE 14. Impact Assessment Steps (Bender, 1977)

# APPENDIX
# NOISE AS A STRESSOR*

The concept of noise as a stressor is basic to understanding the nonauditory physiological effects of noise on animals. Stress is often defined by the types of responses of the stressed organism. For example, the pioneering stress researcher, Selye, defined stress very generally as "the nonspecific response of the body to any demand" (Selye, 1976, p. 53). Selye, defined stress very generally as "the nonspecific response of the body to any demand" (Selye, 1976, p. 53). Selye also distinguishes between responses to a stressor affecting only one part of the body (such as a minor skin injury) and that which can affect the whole body (such as prolonged and intense radiation). Responses of the former type, in one part of the body, are called the local adaptation syndrome, whereas those of the latter type involving the whole body are called the general adaptation syndrome (Selye, 1976). It should be clear that, depending on the type and intensity, the same adverse stimulus may affect either the entire body or mainly one part. In this context, the nonauditory effects of noise can be considered whole body stress responses.

For purposes of measurement, researchers may define stress in terms of a specific response. For example, one such investigator defines stress as a stimulus that "provokes responses similar to those attributable to increased levels of ACTH" (Ames, 1974, p. 317). ACTH is the abbreviation for adrenocorticotropic hormone, which stimulates the adrenal glands to release cortisol and other corticosteriods such as aldosterone. A similar definition of stress is anything that causes increased cortisol secretion and increased sympathetic nervous activity (Vander, et al., 1975).

Selye first described the stress reaction in 1936, using data from laboratory animals subjected to a number of adverse stimuli (toxic drugs, severe cold, surgical shock, excessive muscular exercise, etc.) This reaction to acute stress involved three stages--alarm, resistance, and exhaustion. The alarm stage consisted of changes in normal body functions in order to deal with the stress. After about 48 hours, some of these physiological functions returned to normal in the resistance stage. If the stressful stimuli were continued for a month or more, the animals reached the stage of exhaustion, in which they were no longer able to resist the stress. In this stage, the initial bodily changes recurred (Selye, 1936).

The physiological responses to stress described by Selye have since been well documented in a variety of laboratory animals as well as in humans. The response of animals to stress is considered to be nonspecific, because a variety of different stressful stimuli can produce similar patterns of physiological effects characteristic of stress. Nevertheless, different stressors do have their own unique effects and individual reactions to stress can vary considerably. The same amount of the same stressor may even provoke different responses in two individuals of the same species (Selye, 1976).

A major explanation for stress having varying effects in different individuals is that stress involves a number of complex neuroendrocrine interactions. An understanding of the normal relationships between neural and hormonal

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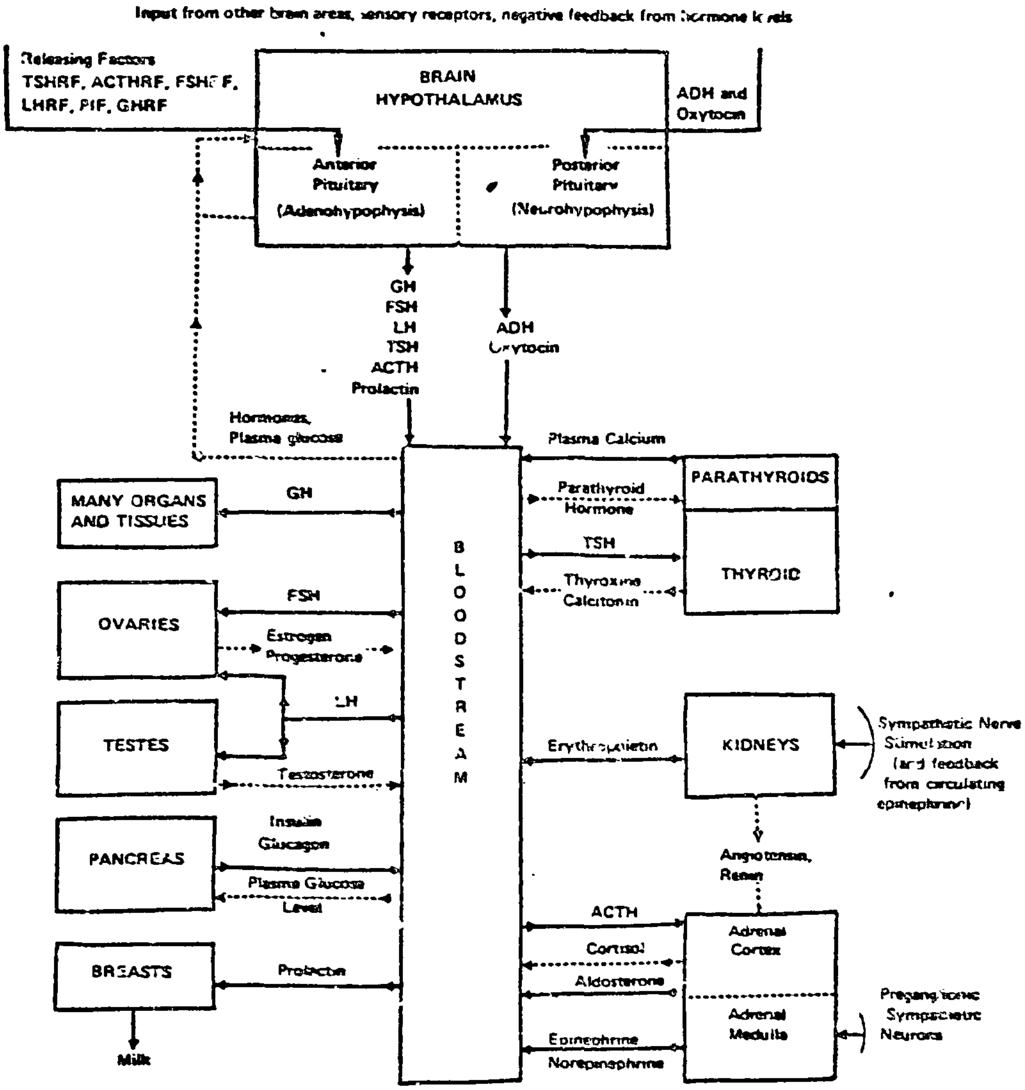
*Dufour (unpublished).

pathways is helpful before the basic physiological responses to stress are outlined. The endocrine system is controlled by neural mechanisms, directly and by negative feedback. The direct neural mechanisms consist of substances (releasing factors) from the hypothalamus in the brain that stimulate the anterior pituitary to release hormones, which induce various endocrine glands to release their specific hormones. The levels of these hormones in the bloodstream also inhibit the rate of the hypothalamic releasing factors and the anterior pituitary hormones (negative feedback). A number of hormones are controlled by feedback mechanisms alone. Some hormones are controlled by both feedback and nervous stimulation. Production of insulin and glucagon by the pancreas is controlled by a feedback mechanism from the amount of glucose (sugar) in the blood. Production of calcitonin (a hormone that lowers calcium and phosphate levels) by the thyroid is similarly affected by the plasma calcium level. The release of renin by the kidneys and the production of angiotensin are controlled by both sympathetic nerve stimulation and by feedback from epinephrine in the blood. The enzyme renin catalyzes the production of angiotensin from angiotensinogen (from the liver). The release of aldosterone (a hormone causing sodium retention) by the adrenal cortex is regulated by the angiotensin level and potassium concentration. The release of the catecholamines (epinephrine and norepinephrine) by the adrenal medulla is controlled by sympathetic neurons (Vander, et al., 1975). Figure A represents a summary of the basic neuroendocrine pathways. The feedback pathways are represented by broken lines.

The word "stress" evokes mostly negative feelings, because of the implication of stress in some serious human diseases, including heart attack, atherosclerosis, ulcers, hypertension, and psychological problems. Although chronic stress may lead to unpleasant consequences, the absence of any stress whatever may make an animal more vulnerable to adverse conditions. The biological origin of the stress reaction is commonly referred to as the "fight or flight" response, which enables an animal to protect itself from attack (from predators, infection, injury, etc). Loud noise in primitive times was usually a signal for alarm. In the 20th century, however, high noise levels are often associated with highway traffic, aircraft, machinery in factories, blasting operations, and a number of other ordinary sources. Although there may be no reason to fear these sounds, the same primitive physiological stress reactions may be induced. These "inappropriate" reactions to noise and other stressors may be the sources of the nonauditory effects associated with chronic exposure in humans (Moller, 1975; Selye, 1976). Problems due to stress reactions in wildlife (as in humans and laboratory animals) deserve further study.

The basic stress response model, compiled from several sources (Selye, 1976; Vander, et al., 1975; Holvey, 1972) involves increased sympathetic nervous system activity and increased cortisol levels. The sympathetic and the parasympathetic nervous systems make up the autonomic (or involuntary) nervous system, which controls the cardiac muscle, the smooth muscles of the internal organs and the glands, and maintains homeostasis. The parasympathetic system mainly regulates internal body functions, while the sympathetic system is mainly involved in responding to stress and other outside influences. Since the symapthetic nerves affect many body functions, it is understandable that increased activity in these nerves can result in alterations in a number of parameters. The increased cortisol level is due to stimulation of the hypothalamus, which causes the anterior pituitary to release more ACTH (influenced by ACTH Releasing Factor), which stimulates the adrenal cortex to release more cortisol.



Abbreviations:

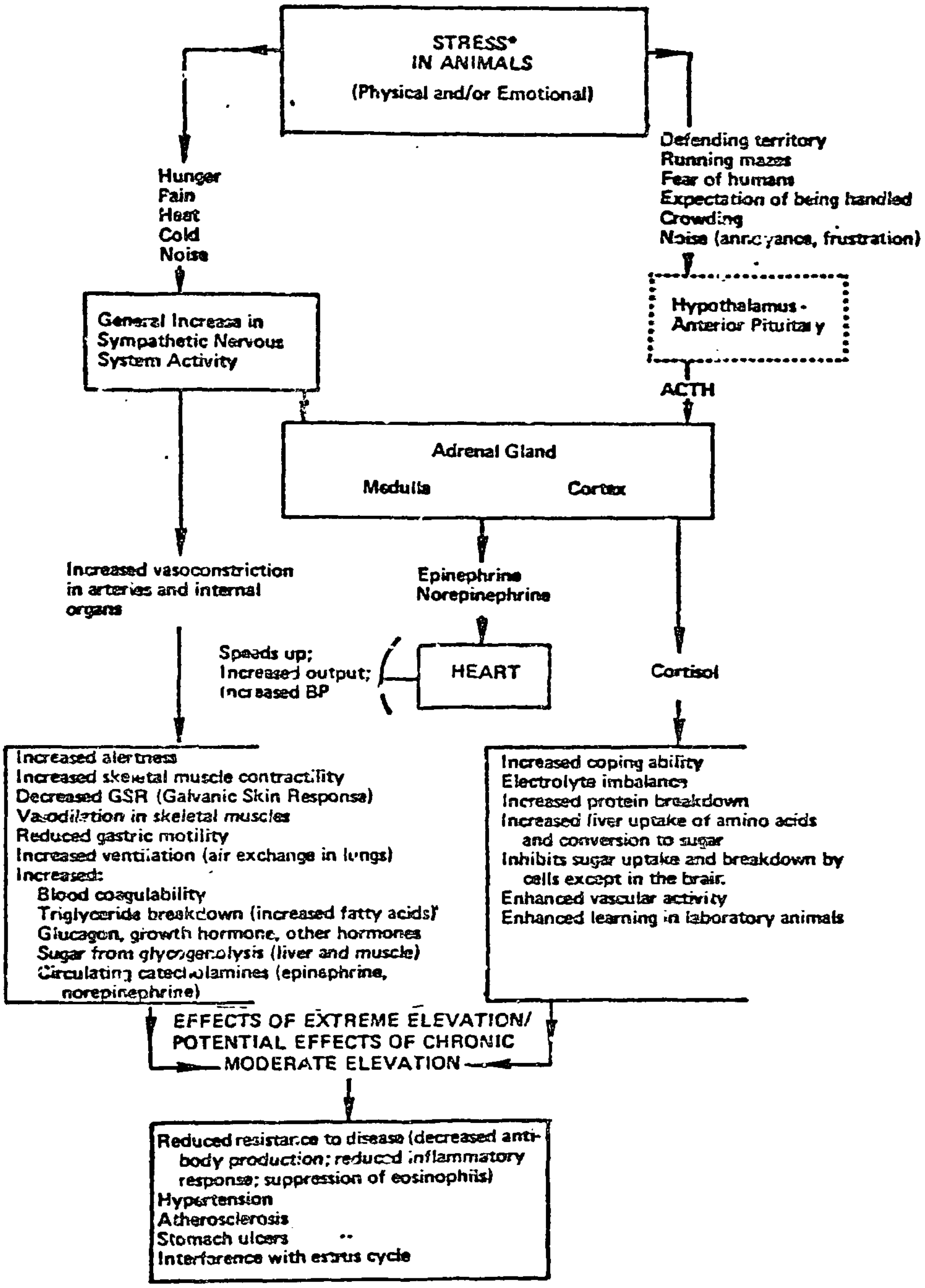
| | | | | | |
|---|---|---|---|---|---|
| TSH | = | Thyroid Stimulating Hormone | TSHRF | = | TSH Releasing Factor |
| ACTH | = | Adrenocorticotropic Hormone | ACTHRF | = | ACTH Releasing Factor |
| FSH | = | Follicle-Stimulating Hormone | FSHRF | = | FSH Releasing Factor |
| LH | = | Luteinizing Hormone | LHRF | = | LH Releasing Factor |
| GH | = | Growth Hormone* | GHRF | = | GHRF Releasing Factor |
| ADH | = | Antidiuretic Hormone (Vasopressin) | PIF | = | Prolactin Inhibiting Factor |

FIGURE A. Neuroendocrine Pathways.

Cortisol (or hydrocortisone), like the sympathetic nerves, affects many organs and tissues. Its functions under normal (nonstress) conditions involve protein and carbohydrate metabolism, water and electrolyte balance, muscle tone, and increased gastric secretion. Higher cortisol levels during stress result in increased protein breakdown, increased blood sugar, electrolyte imbalance, and increased vascular activity. Cortisol has sometimes facilitated learning in laboratory animals through an unknown mechanism (Vander, et al., 1975).

Although cortisol is the major hormone increased by stress, all other hormones seem to be affected. Other hormones that are increased during stress are prolactin (induces lactation), glucagon (increased blood sugar and fatty acids), thyroxine, growth hormone, aldosterone, and antidiuretic hormone (ADH). Thyroxine controls growth and a number of metabolic functions. The last two increase water retention, whereas growth hormone may stimulate tissue repair. Hormones that decrease during stress are testosterone, estrogen, insulin, LH (luteinizing hormone), and FSH (follicle stimulating hormone).

Figure B summarizes the major effects of acute stress and lists the potential effects of chronic stress.



*Also known as the "fight or flight" response

FIGURE 8. Stress Responses

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