NR-4

Natural Resources

Review of Literature on the Effects of Noise on Livestock and Wildlife

APPENDIX NR-4: REVIEW OF LITERATURE ON THE EFFECTS OF NOISE ON LIVESTOCK AND WILDLIFE

Introduction

This appendix reviews some of the more important concepts and conventions for sound in air and water, and its effect on livestock and wildlife. Unless specific references are given, standard texts on acoustics are the sources of information and can be consulted for details. Recommended texts include Richardson *et al.* (1995), Urick (1983), Beranek (1986), and Pierce (1989).

Pressure and Sound

Sound is usually viewed as a disturbance of the pressure of a medium, and can be described in terms of the pressure changes in space and time relative to the average pressure of the medium, which itself may be moving. As the pressure wave propagates, the medium is alternately condensed and rarefied. Pressure is a force per unit area and is non-directional. The pressure disturbance, however, may propagate as a wave through the medium, giving the sound a directional character. As defined, the average sound pressure over time at a specific location must be zero, or it would change the static pressure and no longer be treated as a disturbance.

Pressure in itself as a force does not perform work or generate energy. Static pressure in a non-moving medium has no energy. However, a pressure disturbance or wave causes motion of particles of the medium in propagating, and thus generates energy. This is the type of energy of interest in the treatment of sound. It is emphasized that the average or static pressure of the medium has no impact on the pressure content of a sound wave, nor does it contribute to the energy carried by that wave.

Sound is almost always measured in terms of pressure, namely the pressure disturbance in time and location. In most situations, away from sources and boundaries, other properties of sound can be calculated from the pressure information: power density, energy flow, peak pressure, positive impulse, and frequency content. These quantities will be addressed below.

Because of the fundamental nature of sound as a pressure disturbance, sound receivers (including human and animal ears as well as microphones and hydrophones) are generally treated as receivers of pressure. Other directly related properties of sound, such as pressure gradient or particle velocity, can generally be viewed as space-time properties of the pressure disturbance.

Pressure, as force per unit area, has standard (SI) units of *Newton per square meter* (N/m^2), which is the same as the derived SI unit of *pascal (Pa)*. Thus, a pressure of one pascal is the same as a force of one Newton applied to an area of one square meter. Because of the sensitivity of animal ears to sound, pressure is usually expressed in terms of millionths of Pascals (i.e., *micropascals* [μPa]). On the other hand, there are many alternate, popular units for pressure, including: pounds per square foot (psf), pounds per square inch (psi), bars, atmospheres (atm), inches of mercury, dynes/cm^2, and others. In spite of attempts at standardization, and a serious cause for confusion, such units continue to be used in all branches of fluid technology today. For perspective, note that 20 μPa, usually taken as the smallest pressure disturbance that a healthy human ear can detect, is about the same as 2.9 x 10^{-9} psi or 4.2 x 10^{-7} psf or 2 x 10^{-10} atm.

Scientists who study sound determined that people hear logarithmically, meaning the ear distinguishes between sounds that are very weak or very strong through means of a complicated nonlinear response. In addition, the dynamic range of the ear is very large (from about 20 μPa to over 20,000,000 μPa). A logarithmic scale, denoted as decibels (dB), to measure sound powers was thus developed as a practical convenience. Since sound power is proportional to squared pressure, the decibel is used to define *sound pressure level (SPL)* as:

SPL = 10 $\log_{10}$(squared pressure/squared reference pressure) dB (re ref pressure)

By convention and tradition, the reference pressure usually used for air is 20 μPa and for water 1 μPa. Examples:

20 μPa = 10 $\log_{10}$ [20 μPa$)^2$/(1 μPa$)^2$] = 20 log 20 = 26 dB (re 1 μPa)

20 μPa = 0 dB (re 20 μPa)

10,000 μPa = 100 dB (re 1 μPa) = 74 dB (re 20 μPa)

The frequency of sound is important both for the physical properties of the wave and for the effect on humans and animals. It is the rate of oscillation of the wave, usually expressed in hertz (Hz), (wave) cycles per second. The kHz (kilohertz) represents 1,000 Hz and is also commonly used for sound. A pressure wave of a single frequency is called a *tone*. A sound wave is more often made up of pressures at many frequencies, covering a *band*. *White noise*, for example, is sound with all frequencies equally represented.

Decibel measurements of sound in air are often weighted to the frequencies that humans hear best. With A-weighting, certain frequencies of the sound are filtered out or given reduced power, so that the remaining frequencies are those that would normally be heard by human ears. Sound frequencies that humans cannot hear, for example above 50 kHz, are practically eliminated from an A-weighted measure. Measurements of aircraft noise exposure to livestock and wildlife are also often expressed in A-weighted decibels (dBA). The A-weighted level is usually smaller than the unweighted level for the same sound. A sound signal with an SPL of 60 dB that has much low-frequency content, such as for aircraft noise, may have a weighted level of only 50 dBA because the sounds at frequencies below those of good human hearing have been given less weight. Weighted levels are used for sound in air, and by convention are referenced to 20 μPa.

Noise Levels Generated by Aircraft

Subsonic and supersonic (sonic booms) noise from the F-22 and various other aircraft at altitude are presented in tables NR4-1 and NR4-2 below.

Table NR-4-1. Sound Exposure Levels (SEL) in dB Under the Flight Track for Aircraft at Various Altitudes in the Primary Airspace[1]								
Aircraft Type	***Airspeed***	**ALTITUDE IN FEET ABOVE GROUND LEVEL**						
		300	***500***	***1,000***	***2,000***	***5,000***	***10,000***	***20,000***
F-15C	520	116	112	107	101	85	80	65
F-22[2]	520	118	114	108	101	89	77	62
F-16A	450	110	107	101	95	85	74	59
F-18A	500	118	114	108	101	89	77	62
F-14A	530	112	109	103	96	84	73	58
B-1B	550	116	112	107	101	92	82	70

Notes: 1. Level flight, steady high-speed conditions.
2. Projected based on F-22 composite aircraft.

Table NR-4-2. Sonic Boom Peak Overpressures (psf) for F-15C and F-22 Aircraft at Mach 1.2 Level Flight				
	ALTITUDE (FEET)			
Aircraft	***10,000***	***20,000***	***30,000***	***40,000***
F-15C	5.40	2.87	1.90	1.46
F-22	5.68	3.00	1.97	1.50

Animals and Aircraft Noise

Animal responses to aircraft are influenced by many variables including aircraft size, speed, proximity (both height above the ground and lateral distance), engine noise, color, flight profile, and radiated noise. The type of aircraft (e.g., fixed-wing versus rotor-wing [helicopters]) and its flight mission may also produce different levels of disturbance and animal response (Smith *et al.* 1988).

The potential sources of impacts to livestock and wildlife from aircraft overflights are the visual effects of the aircraft and the associated noise: persistent noise for subsonic aircraft or sonic boom noise for supersonic flight. Any visual impacts would be most likely to occur when airspace use is below 1,000 feet above ground level (AGL), the altitude accounting for most reactions to visual stimuli by animals (Lamp 1989, Bowles 1995). However, with the exception of takeoffs and landings, and a few areas that could experience flights as low as 500 AGL, the F-22 would not train below 1,000 feet AGL. Indeed, the projected percent of F-22 flight hours below 1,000 feet AGL is 0.25 percent.

Noise effects to livestock and wildlife are classified as primary, secondary, and tertiary effects. Primary effects are direct, physiological changes to the auditory system, (i.e., ear drum rupture, temporary and permanent hearing threshold shifts, and the masking of auditory signals). These permanent, primary effects are not expected to occur from the F-22 overflights because the F-22 does not produce the sustained or sudden noise levels necessary to cause these reactions. Some temporary hearing threshold shifts could occur from sonic booms but there is insufficient research available at this time to determine the level of response by animals that could be exposed to these impacts. Secondary effects include non-auditory effects such as stress and associated physiological response (i.e., increased blood pressure, use of available glucose, and blood corticosteroid levels); behavior modifications; interference with mating or reproduction; and impaired ability to obtain adequate food, cover, or water. The possibility of secondary effects occurring are more likely than primary effects and will be explored in detail as follows. Tertiary effects are the direct result of primary and secondary effects, and include population declines, habitat loss, and species extinction. Tertiary effects of aircraft overflight are difficult to pinpoint because the intricate details involved in ecosystem function include many factors not related to the overflight operations.

Behavioral experiments have demonstrated that noise at high levels is mildly aversive in and of itself, apparently because the physiological effects stimulated by noise are aversive (e.g., muscular flinch and rapid breathing) (Bowles 1997). However, noise is not aversive enough to be an effective conditioning stimulus over the long term. This explains the failure of most acoustic harassment devices to deter wildlife, such as deer, from favored areas (Bowles 1997). Wild animals exposed to intense noise with sudden onset can panic and injure themselves or their young; however, this is usually the result of active pursuit (such as the perceived pursuit of a low flying aircraft). Animals control their movements to minimize risk. Loss rates have varied greatly in the few documented cases of injury or loss. Mammals and raptors appear to have little susceptibility to those losses, whereas the most significant losses have been observed among waterfowl. Panic responses became less with each recurrence, usually disappearing completely with fewer than five exposures (Bowles 1997).

Literature available on effects of aircraft overflights on animals related to the actions proposed for the F-22 activities includes jet aircraft subsonic and supersonic overflight studies conducted in the early 1970s through mid-1999. In the past, literature that discussed different types of aircraft was used to argue whether any aircraft overflights adversely affected animals. Much of this literature discussed helicopter overflight, which is not relevant to the F-22 action. It is found that helicopters have a greater effect on animals than fixed-wing aircraft because they often travel at slow speeds, hover, and fly at low altitudes. Additionally, helicopters are often used to chase, dart, and capture wildlife and could cause a greater fear factor among affected wildlife populations.

The response to sonic booms or other sudden disturbances is similar among many species (Moller 1978). Sudden and unfamiliar sounds usually act as an alarm and trigger a “fight or flight” startle reaction. However, sonic booms are not expected to cause more than a temporary startle-response because the “pursuit” would not be present. The startling effect of a sonic boom can be stressful to an animal. This reaction to stress causes physiological changes in the neural and endocrine systems, including increased blood pressure and higher levels of available glucose and corticosteroids in the bloodstream. Continued disturbances and prolonged exposure to severe stress may deplete nutrients available to the animal.

Some caution has also been suggested when extrapolating studies using a different type of aircraft (helicopter versus fixed-wing), or for one species for the results that might happen for another. For this reason, only studies relating to fixed-wing aircraft and species potentially affected by the F-22 proposals will be used to discuss impacts, except when used for comparison purposes.

Most of the effects of noise are mild enough that they may never be detectable as changes in population size or population growth against the background of normal variation (Bowles 1995). Many other environmental variables (e.g., predators, weather, changing prey base, ground-based human disturbance) may influence reproductive success and confound the ability to identify the ultimate factor in limiting productivity of a certain nest, area, or region (Smith *et al.* 1988). In contrast, the effects of other human intrusions near nests, foraging areas, dens, etc. (e.g., hiking, bird watching, timber harvesting, boating) are readily detected and substantially affect wildlife behavior and reproductive success (United States Forest Service [USFS] 1992).

The following discusses the aircraft overflight effects on animals.

Domestic Animals

A large bibliography of studies on the effects of aircraft noise on livestock has found a varied effect, although many of the studies suggest a minimal effect of aircraft overflight on the health and well-being of these animals. The following is a summary of the literature findings by major domestic animal types found in the area that would be overflown by the F-22. Although some studies report that the comprehensive effects of aircraft noise on domestic animals is inconclusive, a majority of the literature reviewed indicates that domestic animals exhibit minimal behavioral reactions to military overflights and seem to habituate to the disturbances over a period of time. There is no evidence from these studies that aircraft overflights affect feed intake, growth, or production rates in any way.

Cattle and Sheep

A study in Sweden found that no adverse effects were observed in cattle and sheep, and behavioral reactions were considered minimal in 20 cattle and 18 sheep that were exposed to 28 sonic booms and 10 low-altitude subsonic flights over four days (Espmark *et al.* 1974). The authors determined there was a strong tendency for the animals to adapt to aircraft overflight disturbance, which would minimize any long-term effects.

In response to concerns about overflight effects on pregnant cattle, cattle safety, and milk production, the Air Force prepared a handbook for environmental protection that summarizes the literature on the impacts of low-altitude flights on livestock (and poultry) and includes specific mention of case studies conducted in numerous airspaces across the country. Negative results have been found in a few studies, but are not reproduced in other similar studies. One study in 1983 suggested that 2 of 10 cows in late pregnancy aborted after showing rising estrogen and falling progesterone levels correlated with 59 aircraft overflights, while the other 8 cows showed no changes in their blood concentrations and calved normally (Air Force 1993). A study in 1982, showed abortion results in 3 out of 5 pregnant cattle after exposing them to flyovers by six different aircraft (Air Force 1993). A third study in 1983 suggests feedlot cattle could stampede and injure themselves when exposed to low-level overflight (Air Force 1993).

Negative findings were few, however, and the findings of little or no effect were more prevalent. A study in 1978 by Rowe and Smithies examined the causes of 1,763 abortions in Wisconsin dairy cattle over a one-year time period and none were associated with aircraft disturbances (Air Force 1993). In 1987, Anderson contacted 7 livestock operators for production data, and no effects of low-altitude and supersonic flights were noted. Three out of 43 cattle previously exposed to low-altitude flights showed a startle response to an F/A-18 aircraft flying overhead at 500 feet AGL and 400 knots by running less than 10 meters. They resumed normal activity within 1 minute (Air Force 1993). A study (Beyer 1983) found that helicopters caused more reaction than other low-aircraft overflights, and even the helicopters at 30 to 60 feet overhead did not affect milk production and pregnancies of 44 cows and heifers in a 1964 study (Air Force 1993). Additionally, the 1983 Beyer study showed that 5 pregnant dairy cows in a pasture did not run or disturb their pregnancies after being overflown by 79 low-altitude helicopter flights and 4 low-altitude, subsonic jet aircraft flights (Air Force 1993). A 1956 study found that the reactions of dairy and beef cattle to noise from low-altitude, subsonic aircraft were similar to those caused by paper blowing about, strange persons, or other moving objects (Air Force 1993). In addition, Broucek (Air Force 1992) found that dairy cows react to the sound of a tractor engine (97 dB) with an increased white blood cell count (the cells that fight infection), an increased sugar reserve in the blood (a response to adrenaline or fear) and a lowered red blood cell count (cells that carry oxygen to the body) (Gladwin *et al.* 1988). Overall, the USFS has concluded in a report to Congress (USFS 1992) that "evidence both from field studies of wild ungulates and laboratory studies of domestic stock indicate that the risks of damage are small (from aircraft approaches of 50 to 100 meters), as animals take care not to damage themselves. If animals are simply overflown by aircraft at altitudes of 50 to 100 meters, there is no evidence that mothers and young are separated, that animals collide with obstructions (unless confined) or that they traverse dangerous ground at too high a rate." These varied study results suggest that, although the confining of cattle could magnify animal response to aircraft overflight, there is no proven cause-and-effect link between startling cattle from aircraft overflights and abortion rates or lower milk production in cattle.

Horses

Horses have been observed for reactions to overflights as well. Several studies were summarized showing a varied response of horses to low-altitude aircraft overflights. Observations made in 1966 and 1968 noted that the horses galloped in response to jet flyovers (Air Force 1993). Bowles (1995) cites Kruger and Erath as observing horses exhibiting intensive flight reactions, random movements, and biting/kicking behavior. However, no injuries or abortions occurred, and there was evidence that the mares adapted somewhat to the flyovers over a month's time (Air Force 1993). Although horses notice the overflights, it does not appear to affect their survivability or their procreation, and they do seem to habituate to these disturbances.

Hogs

Simulated aircraft noise at levels of 100 dB to 135 dB had no adverse effect on the rate of feed utilization, weight gain, food intake, or reproduction rates of boars and sows exposed, nor were any injury or inner ear change observed (Manci *et al.* 1988, Gladwin *et al.* 1988).

Turkeys

Low-level overflights can cause turkey flocks, kept inside turkey houses, to occasionally pile up and experience high mortality rates due to the aircraft noise and a variety of disturbances unrelated to aircraft (Air Force 1993).

Wildlife

Large Herbivores

Large wild herbivores under the F-22 airspace include caribou, white-tailed deer, mule deer, elk pronghorn antelope, California big horn sheep, Dall sheep, and moose. There have been many studies of aircraft noise on mammals. Some of these studies have examined the noise response of mammals under laboratory conditions (Weisenberger *et al.* 1996). Other researchers have investigated the physiological and behavioral responses of mammals in the field (Lamp 1987). Laboratory studies previously showed habituation results to continuous noise exposure. Now, both field and laboratory data on large, wild herbivores show that the effects are transient and of short duration and suggest that the animals appear to habituate to noise through repeated exposure without long-term discernible negative effects (Workman *et al.* 1992, Krausman *et al.* 1993, Weisenberger *et al.* 1996). Therefore, minor changes in the number and types of overflight are not expected to result in major impacts to wildlife populations.

Mule Deer

Mule deer were observed for jet fighter overflight responses. None of the three jet fighter flights below 3,000 feet AGL and none of the 18 jet fighter flights above 3,000 feet AGL caused mule deer to run (Kroodsma 1988).

Caribou

Only studies of fixed-wing aircraft overflight effects on caribou are included in this summary since helicopters cause a different reaction to this group of animals. A study by Calef *et al.* (1976) found that caribou react strongly to low aircraft overflights below 500 ft AGL and recommended that flying minimum aircraft altitudes of 500 feet AGL be employed during the summer and fall migrations, and 1,000 feet AGL be employed at other times, especially during calving season. With rare exception, the F-22 is not planned to fly in the MOAs below 1,000 feet AGL, and no flights are expected below 500 feet AGL, so no adverse effects to caribou are anticipated.

Bowles *et al.* (1991) summarized a study by Harrington and Veitch conducted in 1989 that measured long-term effects on caribou use of their habitat when overflown by military jet aircraft at 100 to 500 feet AGL every 3 to 4 days. Two herds were exposed to this activity, and one was not, but kept as a control group. During the lowest overpasses (100 feet AGL), only 3 to 10 percent of the animals ran for an average of 5 seconds. No injuries or deaths were observed as a result of these responses. The distances traveled per day, the home range area, and total range did not differ between the control and experimental groups. Bowles *et al.* (1991) also summarized Valkenburg and Davis study in 1985 that measured the reproductive success of caribou in an area that had high rates of human disturbance, including harassment from aircraft, and found calving rates comparable to those in other areas of the same range with the same predator abundance, a strong factor in caribou calf mortality. Bowles *et al.* (1991) also found numerous studies also support the thought that the caribou do not respond as readily to aircraft when the risks or costs to them are high. While mothers and young calves are more likely to move when disturbed if calves are able to get around on their own; mothers are very unlikely to move just after calving when calves are still too weak to follow. During the particularly stressful insect season, caribou are unlikely to respond to aircraft disturbance. They are also less likely to run in rough terrain where they can injure themselves more easily. Although the extent of reactions to aircraft overflight by caribou is in debate, the general consensus is that the effect of aircraft overflights on caribou behavior is not catastrophic.

A study by Davis *et al.* (1985) noted that most researchers agree that caribou are most sensitive during calving. However, a caribou herd and one of its traditional calving grounds have been subjected to low-flying helicopters and jet fighters and bombers every weekday to support training, bombing, strafing, and artillery firing over this area since at least the 1970s. Nevertheless, the herd has continued to use its traditional calving ground and has had one of the highest annual growth rates of any Alaskan caribou herd.

Dall Sheep

The National Park Service summarized studies on Dall sheep responses to aircraft overflight. When helicopters were involved, the responses included running. However, in a study by Nichols in 1972, the Dall sheep either showed no response or they would get excited but would not abandon the habitat.

Moose

Although studies on moose reactions to fixed-wing aircraft are not well documented, moose would not react to helicopters that were 600 feet AGL or higher (Doll *et al.* 1974). In general, helicopters elicit greater responses from wildlife than do fixed-wing aircraft. Evans *et al.* (1966) noted that moose are not disturbed by aircraft unless the plane is very close. Animals bedded down may rise but not move away; animals standing or feeding may look up. Only rarely do the moose make a short run from an airplane.

Bison

Bison do not react as strongly to surrounding disturbances, as do cattle. A study in 1972 by Frazier observed bison with high and low-altitude (100-1,000 feet AGL at 450 knots) overflights with F-15 aircraft at a ground noise level of 90 dBA; the bison “appeared oblivious” to the aircraft noise and continued grazing throughout all aircraft passes (Gladwin *et al.* 1988). Aircraft overflights appear to have little, if any, effect on bison.

Small Mammals

Small mammals make up the majority of mammalian biological diversity under airspaces associated with the proposed action and its alternatives. Typical small mammals include muskrat, gray squirrel, fox squirrel, Townsend's ground squirrel, deer mouse, bushy-tailed woodrat, beaver, porcupine, pocket mice, voles, Ord's kangaroo rat, gopher, as well as a variety of shrew and mole species.

One recent three-year study by McClenagham and Bowles (1995) focused on chronic military aircraft exposure. It was conducted in south-central Arizona characterized by creosote and mixed Sonoran Desert scrub. The sites were exposed to low-altitude flights of more than 20,000 sound events in excess of 80 dB with 115 dB being the highest A-weighted sound exposure level (SEL) recorded. The control sites received noise levels at least an order of magnitude lower with an average of 51 dB, and none were over 100 dB. The control area event rate was approximately one flight per day. Numerous kangaroo rat and pocket mouse species and the white-throated wood rat were included in the study. Population densities, body weight, reproductive activity, recruitment by immigration and reproduction, and survival rate, were measured. Overall, the outcome of the study suggests the effects of lifetime exposure to intermittent aircraft noise on animal demography are likely to be small and difficult to detect, if they exist at all (McClenaghan and Bowles 1995), which is consistent with what is found in laboratory species and humans (Kryter 1984).

Other Terrestrial Mammals

Other terrestrial mammals occurring under airspace associated with the proposed action and its alternatives include carnivores (fisher, martin, skunk, badger, otter, raccoon, cougar, bobcat, lynx, black and brown bear, coyote, red fox, wolf), and nine banded armadillo, Virginia opossum, and bats. Studies of terrestrial mammals have shown that noise levels of 120 dBA can damage mammals' ears, and levels at 95 dBA can cause temporary loss of hearing acuity. Noise from aircraft has affected other large carnivores by causing changes in home ranges, foraging patterns, and breeding behavior. One study recommended that aircraft not be allowed to fly at altitudes below 2,000 feet AGL over important grizzly and polar bear habitat (Dufour 1980). Wolves have been frightened by low-level flights that were 25 to 1,000 feet off the ground. However, wolves have been found to adapt to aircraft overflights and noise as long as they are not being hunted from aircraft (Dufour 1980, Mech 1970).

Marine Mammals

All marine mammals are protected from injury and harassment under the Marine Mammal Protection Act (MMPA). Mammals specified in the law as marine mammals include cetaceans (whales, dolphins, porpoises), pinnipeds (seals, sea lions), walrus, sirenians (manatees and dugongs), sea otters, and polar bears. Certain species are additionally protected by the Endangered Species Act (ESA), including sperm whales, manatees, many of the baleen whales, and certain pinnipeds. The MMPA specifically forbids such harassment of marine mammals as interference with feeding, breeding, or breathing.

Numerous events of aircraft disturbance of marine mammals have been observed, and Richardson *et al.* (1995) provides a useful summary. Sections below address the impact of subsonic and supersonic noise sources for cases of mammals in air (especially hauled out seals and sea lions) and mammals under water.

Effects of Airborne Noise in Air on Marine Mammals (Pinnipeds - Seals and Sea Lions)

Both physiological and behavioral responses to sonic booms have been examined among California pinnipeds during haulout (Manci *et al.* 1988). The physiological study demonstrated recognizable short-lived changes in hearing sensitivity due to minimum sonic boom overpressures. Longer temporary hearing losses are likely to occur for exposures greater than those tested (Manci *et al.* 1988).

Harbor seals, California sea lions, northern fur seals, and Guadalupe fur seals at the Channel Islands will startle in response to sonic booms of any intensity, and many will move rapidly into the water depending on the season and amplitude of the boom. However, any observed response is usually short-lived. Elephant seals will startle in response to sonic booms of low intensity, but they resume normal behavior within a few minutes of the disturbance (Manci *et al.* 1988).

A missile launch effect of 127 dB (108 dBA) caused 20 of 23 of the Purisima Point harbor seals to flee into the water, and only 3 returned after 2.5 hours. At Rocky Point, 20 of 74 harbor seals fled into the water during a 104 (80 dBA) launch event, returning after 30 minutes. Another launch (99 to 102 dBA) caused almost all Rocky Point harbor seals ashore to flee into the water, after which 75 percent returned with 90 minutes (Tetra Tech, Inc. 1997).

Titan IVB missiles launched from SLC-4E created focused sonic booms over the northern Channel Islands but had no observable significant impact to biota of San Miguel Island (Versar 1991). None of the studies summarized in the Final Programmatic Environmental Assessment for the Marine Mammal Take Permit showed injury or pup abandonment during all noise levels and sonic boom overpressures observed from any launch site, although temporary abandonment of haul-out places were of a longer duration for those areas subject to higher noise levels (Tetra Tech, Inc. 1997). A study on hearing loss that could be caused by sonic booms did not find any change in harbor seal hearing, although a mild temporary threshold shift in the 2 hours after a sonic boom event and before the testing was conducted could have occurred (Thorson *et al.* 1998).

Effects of In-Water Noise on Marine Mammals

The impact of man-made noise on marine mammals in water is a high-visibility and controversial topic among both scientists and environmental planners. Special attention from the regulators and the public has been given to seismic exploration sources, Navy sonars, and explosives. Impact from aircraft noise in water has been studied to a limited extent, and the MMPA/ESA risk is generally insignificant, as discussed below.

Marine mammal hearing capabilities vary greatly among species. This can be very important in assessing risk from noise, especially aircraft noise.

Hearing tests have been performed on only a few species of the smaller marine mammals, usually in captivity: certain dolphins, seals, sea lions, and manatees. Hearing capabilities of other marine mammals are estimated from anatomy of the ear and from at-sea observations vocalizations and reactions to sound. Although knowledge of marine mammal hearing is generally poor, it is not unusual in risk assessments to find marine mammals classified according to high and low hearing bands:

> Class H: Those that have most sensitive hearing above 1,000 Hz, and poor hearing below 1,000 Hz. These include all toothed whales (odontocetes) except for sperm whales which occur in both classes, most pinnipeds (seals and sea lions), and sirenians (manatees). Best hearing for small odontocetes is generally in the range from about 10 kilohertz (kHz) to 80 kHz, and measurements show very poor hearing below about 200 Hz.
>
> Class L: Those that have sensitive hearing below 1,000 Hz. These include all baleen whales (mysticetes), the sperm whale, California sea lions, and elephant seals. Vocalizations of the baleen and sperm whales suggests hearing capabilities as low as 10 Hz, but hearing capabilities above 1,000 Hz are not known. A limit of 25 kHz is sometimes used.

Note that the band of human hearing straddles these bands, with best responses from about 20 Hz to 10 kHz. For more on marine mammal hearing bands, see Richardson *et al.* (1995) or recent compliance documents, such as the SEAWOLF Shock Test FEIS (1998).

In-Water Noise Criteria and Thresholds for Harassment and Injury – Sonic Boom Noise.

Sonic boom noise in air and in water is generally treated as "impulsive noise," meaning that the sound has short duration, a sharp onset or rise-time, and broad frequency content. Other noise sources treated as impulsive by the regulators include airguns, explosives, and sparkers. Recent precedent for criteria and thresholds for injury and harassment under MMPA have been calculated. Table NR-4-3 below provides some relevant examples of thresholds used in recent compliance work. In the table, decibel quantities for energy flux density are referenced to 1 μPa^2-s, where the energy flux density is the integral over the signal duration of the squared pressure, normalized by impedance.

Table NR-4-3. Examples of NMFS Harassment Noise Criteria and Thresholds		
Criterion	*Threshold*	*Reference*
Level B Harassment TTS	Maximum EFD level over all 1/3-octave bands above 100 Hz > 182 dB for mammals in Class H	SEAWOLF Shock Trial FEIS and NMFS Final Rule (1998)
Level B Harassment TTS	Maximum EFD level over all 1/3-octave bands above 10 Hz > 182 dB for mammals in Class L	SEAWOLF Shock Trial FEIS and NMFS Final Rule (1998)
Injury - Eardrum Rupture	EFD in excess of 1.2 psi-in (205 dB)	SEAWOLF Shock Trial FEIS (1998)
Injury -PTS	RMS pressure level exceeds 190 dB (re 1 μPa)	HESS committee, as discussed at NMFS criteria workshop (1998)

Here, TTS (temporary threshold shift) and PTS (permanent threshold shift) are degradations in hearing, sometimes treated by regulators as harassment criteria for mammals under the MMPA and ESA.

In-Water Noise Criteria and Thresholds for Harassment and Injury Regarding Continuous Noise.

Noise from the F-22 flying at subsonic speeds is continuous in nature, meaning that it is persistent in time (non-impulsive). As such, the metrics, criteria and thresholds for impact on marine mammals are quite different from those for impulsive noise. The metric of choice is the intensity level (or rms pressure level or SPL), sometimes with exposure time as a parameter.

Recent precedents for compliance actions show a wide range of opinion as to what noise properties may harass or injure animals (under the MMPA). Levels for physical injury from continuous signals are usually linked to PTS. Typical conditions for Level B harassment are as follows:

> For continuous noise of order seconds in duration and in the band of hearing of the animal, behavioral harassment (Level B for MMPA) may occur for sound pressure levels in excess of 180 dB (re 1 μPa). Longer exposures to aircraft noise may require a decrease in the threshold to levels as low as 175 dB. This applies to all marine mammals. This is approximately the approach used in various Navy "LWAD" environmental assessments, and as approved by the regulator (NOAA/NMFS). The levels are extrapolated from Schlundt *et al* (2000) and from Richardson *et al.* (1995).

Note that other examples can be given with higher thresholds (e.g., TTS for tactical sonar signals) or lower thresholds (e.g., low-frequency active sonars).

Propagation of Sound from Air to Water.

Propagation of sound from air to water is a complicated topic, and very important for risk estimation. It is discussed in a number of acoustics books (e.g., Brekhovskikh and Lysanov 1981). The most important features are summarized as follows:

> Because of the large mismatch of impedances between air and water (a factor of about 3,500), there exists a "critical angle" of about 13 degrees, measured from the vertical, at the air-sea interface.

For a pressure wave arriving at the interface at angles steeper than 13 degrees, the wave is transmitted into the water and propagates at a shallower angle (as determined by Snell's law) in the water. The pressure in the water at the interface is double the incident pressure, and falls off according to propagation conditions in the water column. During training, a large portion of sonic boom events occur during diving associated with simulated combat or defensive maneuvers. Thus, incident angles of pressure waves with the water's surface are often steep.

For energy incident from air on the sea surface at angles less steep than about 13 degrees, there is no transmission of energy as a propagating wave into the water. Instead, there is only an evanescent wave, or non-propagating wave, whose amplitude decays exponentially with depth in the water. As before, there is a doubling of pressure at the interface, but the impact is limited to a region close to the surface and point of incidence. The wave does not propagate on its own in water, but is "bound" to the pressure field in the air. It thus appears to travel horizontally at the velocity of the aircraft (and is thus subsonic in water for aircraft speeds less than about 1,500 meters per second [m/s] or about Mach 4.5).

As the references listed show, the evanescent decay rate with depth is about (8.7) $2\pi\,\gamma$ dB per wavelength where $\gamma = [(c_2/c_1)^2\sin^2\theta_1 - 1]^{1/2}$ with c the speed of sound, θ the incidence angle measured from the vertical, and indices 1 for air and 2 for water. See Table NR-4-4 for examples of estimates of depth dependence of the evanescent wave from an F-22 sonic boom.

Table NR-4-4. Estimates of Depth Dependence of Pressure and Energy for Evanescent Wave from F-22 Sonic Boom

Mach #	*Altitude*	*Peak at 0 meters*	*Peak at 50 meters*	*Peak at 100 meters*	*EFD at 0 meters*	*EFD at 50 meters*	*EFD at 100 meters*
1.5	1 km	178	143	132	162	136	127
1.5	5 km	166	137	126	152	130	121
1.5	10 km	160	134	123	146	126	118
2.5	1 km	180	154	143	163	144	136
2.5	5 km	167	147	136	152	137	129
2.5	10 km	161	142	132	146	132	125

Note: 'Peak' is peak pressure level in dB re 1 µPa and 'EFD' is energy flux density level is dB re 1 µPa²-s. For reference, a peak pressure of 1 psi = 197 dB and 1 psf is 175 dB.

Note also that the differences in impedance between air and water mean that even though the pressure is about the same on either side of the interface, the intensity (and energy) of the wave are much greater in air than in water (about 31 dB). This is reflected in the thresholds for injury and harassment. Whereas a short-duration signal of level 140 dB (re 1 μPa) [or 114 dB (re 20 μPa)] in air could be harmful to mammal hearing, 140 dB (re 1 μPa) in water is usually considered quite safe for animals and humans.

Impact of Sonic Boom Noise on Marine Mammals

An aircraft in level flight at M times the speed of sound in air produces a shock wave at the "Mach angle" (arcsin [1/M], relative to the aircraft line of flight). M is the "Mach number" and Mach 1 is of order 300 m/s at sea level. The shock wave travels at the speed of sound in air on a path perpendicular to the shock cone, and thus arrives at the air-sea interface with the Mach angle as incidence angle (measured from the vertical). As M increases above 1, the Mach angel decreases, and the angle of incidence with the water becomes steeper. For M = 1.01, the angle is 82 degrees, for M = 2, it is 30 degrees, and for M = 4.3 it is 13 degrees. From the propagation discussion above, notice that it is very important that sonic boom energy from the F-22 (and all military aircraft of record) will arrive at the air-sea interface at an angle less steep than critical, and will not be transmitted into the water as a propagating wave. This is generally true for most airplane maneuvers, most weather conditions, and most sea states.

The basic physics of penetration of sonic booms into water was established by Cook (1970) and Sawyers (1968) during SST research. There has been renewed interest in the topic over the past few years by the National Aeronautics and Space Administration (NASA). See the papers of Sparrow and Rochat during the 1990s, the other papers in the bibliography, and the measurements of Sohn and others (2000). Numerical models and measured data support the original Cook/Sawyers work, although the issue of penetration for high Mach numbers and high sea states is still of some interest.

The strongest conceivable sonic boom generated during air combat training is less than 30 psf, five times the highest level flight boom shown in Table NR-4-2. In that case, the pressure of the surface would be about 0.2 psi, or about 183 dB (re 1 μPa). For a typical sonic boom N wave, the energy level in the greatest one-third octave band above 10 Hz would be about 158 dB (re 1 μPa^2-s). Both values are well below the impulse-noise thresholds for harassment given above indicating the lack of impact on marine mammals of all types.

The above analysis is for level flight. During combat training, aircraft are often diving while at supersonic speeds. Diving increases the incidence angle of the boom on the surface, increasing the efficiency of penetration into the water. However, the margins between level flight incidence angle and the penetration angle, and between worst case pressures and the threshold of impact are so large that no impact is expected.

Impact from Noise Generated at Subsonic Aircraft Speeds

Whereas sonic boom energy is limited to a single angle relative to the airplane line of flight, radiated noise for subsonic flight is nearly omni directional in nature. There will generally be pressure waves incident on the water surface at angles steeper than the critical angle of 13 degrees, as well as arrivals at less steep angles. As before, the pressure doubles at the surface, propagates for the steep arrivals, and decays with depth for the less steep arrivals. For certain ocean conditions, the propagating energy may travel significant distances with low loss intensity. For this reason, a loitering airplane or helicopter may be more worrisome than a supersonic aircraft. Note that there are a number of published papers on the topic of subsonic aircraft noise in water, as indicated in the reference section.

As for military, fixed-wing aircraft travelling at subsonic speeds, noise source levels are generally less than 210 dB (re 1 μPa at 1 m). For typical flight conditions and an altitude of 1,000 feet, the maximum sound pressure level at the sea surface would be no greater than about 155 dB (re 1 μPa), which is well below most harassment thresholds in current use.

Observations of Noise Effect on Marine Mammals

The continued presence of a noise source or multiple sources could cause marine mammals to leave a preferred habitat. Because aircraft noise in the overwater airspaces is mobile and would not persist over any particular area, but would be distributed over the range of airspace blocks, habitat displacement is not expected. Aircraft noise, including supersonic noise presently occurring in the overwater airspace of Eglin, Tyndall, and Langley AFBs from sorties involving a variety of mostly jet aircraft. Survey results reported in Davis *et al.* (2000) indicate that cetaceans occur under all of the Eglin and Tyndall marine airspace.

In a summary by the National Parks Service (1995) of the effects of noise on marine mammals, it was determined that gray whale and harbor porpoise showed no obvious behavioral response to aircraft noise or overflights. Bottlenose dolphins showed no obvious reaction in a study involving helicopter overflights at 1,200 to 1,800 feet above the water. Neither did they show any reaction to survey aircraft unless the shadow of the aircraft passed over them, at which point they may dive (Richardson *et al.* 1995). Human-made noises in the marine environment from ships, pleasure crafts, and other sources may have more of an effect on marine mammals than aircraft noise (USAF 2000). The noise effects on cetaceans appears to be somewhat attenuated by the air/water interface. The cetacean fauna along the coast of California have been subjected to sonic booms from military aircraft for many years without apparent adverse effects (Tetra Tech, Inc. 1997).

Manatees appear relatively unresponsive to human–generated noise to the point that they are often suspected of being deaf to oncoming boats (although their hearing is actually similar to that of pinnipeds) (Bullock *et al.* 1980). Little is known about the importance of acoustic communication for manatees, although they are known to produce at least ten different types of sounds and are thought to have sensitive hearing (Richardson *et al.* 1995). They continue to occupy canals near Miami International Airport which suggests that manatees in urban areas have become habituated to human disturbance and noise (Metro-Dade County 1995). Since manatees spend most of their time below the surface, and since they do not startle readily, no effect of aircraft overflights on manatees would be expected (Bowles *et al.* 1991).

Raptors

Birds of prey, or raptors, in the F-22 airspace areas include prairie falcon, peregrine falcon, osprey, bald eagle, red-shouldered hawk, and red-tailed hawk.

Peregrine and Prairie Falcons

Peregrines occupy their breeding habitat by March 1, with egg laying occurring from March 15 to May 15. During this period of egg laying and initial incubation, peregrines are most susceptible to disturbance and abandonment (United States Fish and Wildlife Service [USFWS] 1984). A study (Ellis *et al.* 1991) of low-altitude overflights above prairie falcon and other similar raptors showed no permanent nest abandonment or reduction in reproductive success. Abandonment is less likely during the period from May 16 until the fledged young have dispersed from the nest area (usually by August 15).

In studies on the impacts of low-altitude jet overflights on nesting peregrine and prairie falcons, Ellis (1981) and Ellis *et al.* (1991) found that responses to extremely frequent and nearby jet aircraft were often minimal and never associated with reproductive failure. Typically, birds quickly resumed normal activities within a few seconds following an overflight. While the falcons were noticeably alarmed by the noise stimuli in this study, the negative responses were brief and not detrimental to reproductive success during the course of the study.

In 1995, a three-year study was initiated for the Air Force by the Alaska Cooperative Fish and Wildlife Research Unit, University of Alaska, Fairbanks, and Alaska Biological Research to assess the effects of jet overflights on the behavior, nesting success, and productivity of nesting peregrine falcons beneath five MOAs in interior Alaska (Ritchie *et al.* 1998). An average of 34 nests per year were monitored over the three-year study, with an average of 28 and 27 overflights each, respectively, through the nesting season. Daily SELs ranged from 60 to 110.6 dBA. Overall, the average number of young per successful pair was greater at the experimental sites than at the control sites (Ritchie *et al.* 1998). These findings suggest factors other than aircraft overflights could have been influencing the falcons' nesting success. The findings also suggest that aircraft overflight is not a negative influence to peregrine nesting activities. This is further supported by Ellis *et al.* (1991) where they observed peregrine falcons and other raptor species nesting in the immediate vicinity of airports under the flight patterns where aircraft land and take off.

The USFWS is monitoring peregrine success within two areas of East Central Alaska (Ambrose 2000). One study location is in and near the Yukon 1 and 2 MOAs ("off-river"). This area has a great deal of low-level training activity, and the 2-mile/2,000 foot AGL flight restrictions are applied here (Ambrose 2000). The second location is along the Yukon River ("on-river") between the Alaska-Yukon Territory border and Circle, Alaska. The upper portion of the on-river area is in the Yukon 3 and 4 MOAs. Very little low-level training occurs here and the 2-mile/2,000 foot AGL flight restrictions apply (Ambrose 2000).

The 1999 monitoring results (the 2000 annual report was not completed at the time of writing) reveal no significant difference in breeding success and productivity between the two areas. The off-river area had 61 percent success among the nesting pairs, and 2.39 nestlings per successful pair (Ambrose 2000).

The 1998 monitoring results also reveal no significant difference in breeding success and productivity between the two areas. The off-river area had 73 percent success among nesting pairs, and 2.45 nestlings per successful pair. The on-river area had 76 percent success among nesting pairs, and 2.21 nestlings per successful pair (Ambrose 1998).

In 1997, reproductive statistics were higher in the off-river area (great deal of low-level training) than in the on-river area (very little low-level training). In the off-river area, 81 percent of nesting pairs were successful and productivity was 2.38 per successful nesting pair within the on-river area (Ambrose 1998).

Low-level military aircraft have the potential to disturb peregrine falcon nesting in the MOAs (Ambrose 2000). Other factors may also influence breeding success including nest site characteristics, weather, prey availability, habitat around the nest, breeding density, presence of environmental contaminants, and age of breeding adults (Ambrose 2000). Recent monitoring results within the two study areas have not revealed significant decreases in breeding success in the off-river study area, which has a high volume of low-level military flights. However, continued monitoring and evaluation of all factors that may influence breeding success and productivity of peregrine falcons is required to better assess potential impacts of low-level military aircraft (Ambrose 2000).

Bald Eagle

Fleischner and Weisberg (1986) have shown that bald eagles are susceptible to being startled by loud noises during the breeding season. Bald eagles, a threatened species, typically respond to the proximity of disturbance, such as from pedestrian traffic or aircraft within 100 m, because of the increased visibility of the perceived threat rather than noise level (Ellis *et al.* 1991). Bald eagles' reactions to commercial jet flight, although minor (e.g., looking), were twice as likely to occur at eagle-jet distances of one-half mile or less (Fleischner and Weisber 1986). Another study by Fraser *et al.* (1985) stated that over 850 overflights of active bald eagle nests only resulted in two eagles (10 percent) that interrupted their incubation or brooding activities during these overflights. Awbrey and Bowles (1990) suggested that eagles are particularly resistant to being disturbed from their nests.

Osprey

Nesting osprey were overflown at 1,000 feet AGL by CF-18 jet aircraft, and the osprey behavior did not appear to agitate or startle them when overflown, even though the noise levels occasionally exceeded 100 dB (Trimper *et al.* 1998).

Other Raptors

Lamp (1989) found in a study of the impacts to wildlife of aircraft overflights at Naval Air Station Fallon in northern Nevada, that nesting raptors (golden eagle, bald eagle, prairie falcon, Swainson's hawk, and goshawk) either showed no response to low-level flights (less than 3,000 feet AGL) or showed only minor reactions. Minor reactions consisted of the bird assuming an alert posture or turning its head and watching the aircraft pass overhead.

Duration of raptor response to aircraft disturbances was monitored for one year and was found to average 14 seconds for low-level overflights. All raptor nests under observation successfully fledged young (Lamp 1989).

A study was conducted in 1984-1985 that looked at the effects of low-level helicopter overflights on 35 red-tailed hawk nests, some of which had never before been overflown (Anderson *et al.* 1989). The red-tailed hawks not overflown previously exhibited stronger avoidance behavior (i.e., 9 of 17 birds flushed from the nest) than the experienced birds (i.e., 1 of 12 birds flushed from the nest). The overflights did not appear to influence nesting success at either study area. These findings are consistent with the belief that red-tailed hawks habituate to low-level air traffic even during the nesting period.

In a literature review of raptor responses to aircraft noise, Manci *et al.* (1988) found that most studies of raptors did not show a negative response to overflights. When negative responses were observed they were predominantly associated with rotor-winged aircraft or jet aircraft that were repeatedly passing within one-half mile of a nest. The USFWS indicated as part of consultations associated with a Cannon AFB action that flights at or below 2,000 feet AGL from October 1 through March 1 could result in adverse impacts to wintering bald eagles (USFWS 1998a). However, Fraser *et al.* (1985) believes that raptors habituate to overflights rapidly, sometimes tolerating aircraft approaches of 65 feet or less.

Raptor response to sonic boom while nesting was investigated through the use of simulated booms in natural conditions. Response to sonic boom was fairly minimal (Ellis *et al.* 1991). The sonic booms generated for response testing were equivalent to impulse noises generated by supersonic jets in the medium- to high-altitude range (2,000-3,000 meters). There was a total of seven raptor species tested including 84 individuals in various life stages. Of the individuals observed during sonic booms, 65 responses were insignificant. Adult response to the sonic boom usually resulted in flushing from the nest, although incubating or brooding adults never left the nesting area. Reactions among species did have some variation. The reproductive rates for the tested sites were at or above normal for both years of testing. Heart rate response to sonic booms were measured using captive peregrine falcons. Heart rates after sonic booms were at or below a heart rate level of a falcon returning from flight (Ellis *et al.* 1991). In a different study on adult peregrine falcons, the startle response was found to cause egg breakage of already thin eggshells (residual dichlorodiphenyl-trichloroethane (DDT) effects) or cause young close to fledgling age to fledge prematurely, thus placing them at a particularly high risk of mortality. Peregrine falcons at the early nesting phase are not adversely impacted sonic booms because the chicks are expected to crouch safely down in their nests rather than move toward the edge of the ledge (Read 1996a).

Other Birds

As opposed to other taxa, many researchers (Bowles 1997, Ellis *et al.* 1991, Pritchett *et al.* 1978) have studied the effects of aircraft noise on birds and mammals. Some of these studies have examined the noise response of birds under laboratory conditions (e.g., Book and Bradley n.d.). These laboratory studies showed animal habituation to continuous noise exposure; however, the studies did not determine whether this response could be duplicated in the field or whether the laboratory conditions artificially created the response. Other researchers have investigated the physiological and behavioral responses of birds in the field (Ellis *et al.* 1991, Henson and Grant 1991). Both the current field and laboratory data, however, indicate that many birds appear to habituate to noise through repeated exposure without long-term discernible negative effects. Loud sonic booms (80-89 dBA SEL) elicited a shorter duration of startle responses than to other disturbances, such as humans on foot, low-flying helicopters, or loud boats (Cooper and Jehl 1980).

Passerines

Manci *et al.* (1988) reported reproductive losses for small territorial passerines (i.e., perching birds or song birds) after exposure to low-altitude overflights. However, it has been observed that passerines cannot be driven any great distance from a favored food by a nonspecific disturbance, such as aircraft overflight (USFS 1992). Further study may be warranted.

Migratory Waterfowl

A low reaction rate was observed among four species of wintering waterfowl near Piney Island, North Carolina, when overflown by military aircraft at 500 feet AGL. Flights occurred as frequently as 44 per hour with sound levels equal to or greater than 80 dBA. This suggests that wintering waterfowl have tolerance to some level of noise on their wintering grounds and that they may have habituated to aircraft noise (Conomy *et al.* 1998a). Another study by Conomy and others (1998b) exposed previously unexposed ducks to 71 noise events per day that equaled or exceeded 80 dBA. It was determined that the proportion of time black ducks reacted to aircraft activity and noise decreased from 38 percent to 6 percent in 17 days and remained stable at 5.8 percent thereafter. In the same study, the wood duck did not appear to habituate to aircraft disturbance. This suggests a species-specific reaction to aircraft disturbance (Air Force 2000). If waterfowl individuals are susceptible to damage as a result of these moderate responses, noise may continue to have an impact over long periods. For example, gulls nesting in colonies can take advantage of brief defensive flights to cannibalize one another's eggs (Burger 1981). Unfortunately, little information is available on the actual extent of such losses. Migrants and animals living in areas with high concentrations of predators are the most vulnerable. Species that are subjected to infrequent overflight do not habituate to overflight disturbance as readily. In studies in Alaska, where overflights were only occasional, snow geese, Canada geese, and brants repeatedly responded to overflights. It has been suggested by researchers that for species not habituated to overflights, the minimum floor of the airspace in these areas should be approximately 1,650 feet for snow geese, and 2,000 to 3,000 feet for brants and Canada geese (Ward *et al.* 1999, Belanger and Bedard 1989).

Wading Birds

Black *et al.* (1984) studied wading bird (e.g., great egret, snowy egret, tricolored heron, and little blue heron) colony effects of low-altitude (less than 500 feet AGL) military training flights with sound levels from 55 to 100 dBA, one or two times per day with three to four aircraft. It was found that reproductive activity, including nest success, nestling survival, and nestling chronology, was independent of F-16 overflights, but was related to ecological factors including location and physical characteristics of the colony and climatology.

Another study on the effects of circling fixed-wing aircraft and helicopter overflight on wading bird colonies found that at altitudes of 195 to 390 feet, there was no reaction in nearly three-quarters of the 220 observations and in 90 percent of the observations, a bird either showed no reaction or merely looked up. Another 6 percent stood up, 3 percent walked from the nest, and 2 percent flushed (but were without active nests) and returned within 5 minutes (Kushlan 1978). Therefore, non-nesting wading birds had a slightly higher chance of reacting to overflights than nesting birds, and gulls that were roosting near a colony in another study remained at the roost when subsonic aircraft flew overhead (Burger 1981). Colonies were found to be distributed randomly with respect to military routes and were more related to wetland types. These results indicated that wading birds were using wetland habitat as colonies as the habitat became available, and this choice was not affected by low-level military overflights (Air Force 2000). The F-22 would not fly lower than 500 feet AGL except on takeoffs and landings that would affect areas already experiencing these kinds of disturbances. Therefore, it can be expected that the F-22 would cause less disturbance to these species during subsonic overflight than what these studies found.

Shore Birds

Burger (1986) studied the response of migrating shorebirds to human disturbance and found that shorebirds did not fly in response to aircraft overflights, but did flush in response to humans and their dogs on the beach. Burger (1981) studies the effects of noise from JFK airport in New York on herring gulls that nested less than 1 kilometer from the airport. Noise levels over the nesting colony were 85 to 100 dBA on approach and 94 to 105 dBA on takeoff. No effects of subsonic aircraft on nesting were noted, although some birds flushed when supersonic aircraft flew overhead and, when they returned, they engaged in aggressive behavior. Groups of gulls tended to loaf in the area of the nesting colony, and these birds remained at the roost when subsonic aircraft flew overhead. Up to 208 of the loafing gulls flew when supersonic aircraft flew overhead. These birds would circle around and immediately land in the loafing flock (Air Force 2000).

Least Tern

Numerous studies and observations have been conducted for the California least tern on Vandenberg AFB, California, culminating in a Biological Opinion for rocket launches near the nesting beaches. According to the Biological Opinion, the California least tern shows a lack of observable impact from nearby large rocket launches or from the pre-launch security patrol fixed-wing overflights. Since the species' exposure to an aircraft flying over their habitat would be far shorter in duration than for the California least terns that were exposed to a rocket launch, it supports a conclusion that the interior least tern would not be expected to show an adverse effect from these brief overflight encounters in the event that they should nest under the airspace.

Snowy Plover

The same Biological Opinion that addressed the California least tern addressed snowy plovers. Snowy plovers were more prone to flush than the California least tern during a launch or pre-launch overflights. Observations detected no impact to the snowy plovers' continued use of habitat areas (wintering or nesting) or nesting success. The monitoring observations from a Delta II launch at Vandenberg AFB found that snowy plovers flushed and settled in a somewhat different flock configuration nesting within 0.5 mile of the launch site. Farther away (about 2.5 miles), no discernible response occurred during launch. The snowy plovers stood from roost sites and walked 1 meter from the original roosting position. The reaction exhibited resembled the response to a perceived predator threat, including a return to normal behavior when the perceived threat had passed (Read 1996a,b).

Fish, Reptiles, and Amphibians

Reptile and amphibians identified under the F-22 airspaces include sagebrush lizard, eastern fence lizard, black racer, black rat snake, eastern diamondback rattlesnake, racerunner, gopher tortoise, sea turtle, wood frog, spotted frog, gopher frog, flatwoods salamander, and bullfrog. The effects of overflight noise on fish, reptiles, and amphibians have been poorly studied, but conclusions about their expected responses have been speculated on through the known physiology and behavior for these taxa (Gladwin *et al.* 1988). Although fish do startle in response to low-flying aircraft noise, and probably to the shadows of aircraft as well, they have been found to habituate to the sound and overflights. The F-22 will not cause shadows since the aircraft will fly no lower than 500 feet AGL except for takeoffs and landings. As with the discussion on underwater noise impact on marine mammals, fish are not expected to be affected by noise from overflights.

Reptiles and amphibians that respond to low frequencies and those that respond to ground vibration, such as spadefoots (genus *Scaphiopus*), may be affected by noise. Limited information is available on the effects of short-duration noise events on reptiles. Dufour (1980) and Manci *et al.* (1988) summarized a few studies of reptile responses to noise. Some reptile species tested under laboratory conditions experienced at least temporary threshold shifts or hearing loss after exposure to 95 dB for several minutes. Crocodilians in general have the most highly developed hearing of all reptiles. Crocodile ears have lids that can be closed when the animal goes under water. These lids can reduce the noise intensity by 10 to 12 dB (Wever and Vernon 1957). On Homestead Air Reserve Station, Florida, two crocodilians (the American Alligator and the Spectacled Caiman) reside in wetlands and canals along the base runway suggesting that they can coexist with existing noise levels of an active runway including DNLs of 85 dB. DNLs are day and night average levels of sound with night sounds given a higher weight because of the potential disturbance to sleep.

A study on the response of desert tortoise to aircraft overflight (maximum exposure 110 dB) and associated sonic booms (maximum exposure 25 psf) found that these impacts did not have significant adverse effects. There was a temporary threshold shift in hearing with most tortoises recovering within one hour after exposure to the sonic boom overpressure. For aircraft noise, there was no apparent startle effect but the tortoises did freeze in place, with slow increases or decreases in activity following thereafter (Bowles *et al.* 1996).

Most species of sea turtle are listed as endangered or threatened, and protected under the ESA. Impact of aircraft noise is not well understood, and is usually treated for compliance purposes in the same way as impact on marine mammals in water (but with emphasis on the hearing band below 1,000 Hz). For reasons discussed under the topic of marine mammals in water, F-22 noise (for subsonic or supersonic flight) is not expected to have impact on sea turtles.

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