NOISE EFFECTS ON ANIMALS: 1998-2002 REVIEW

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Introduction Compared to noise studies on humans, noise effects studies on animals has barely scratched the surface. However, considerable progress has been made in this area over the last five years, especially with respect to marine mammals. Given the allotted space, the authors were not able to provide neither an exhaustive review of each citation nor an extensive list of all work. However, this review provides some of the most notable noise effects studies on animals for the last five years. Brown and Raghu (1998) appropriately categorizes animal noise research by research methodology, but for this review and the readers who might find it useful, the authors chose to subdivide the research, first by terrestrial and aquatic animals, and then by basic taxonomic categories. This method may facilitate a review by readers with specific interests.

Terrestrial Animals - Birds By far the largest number of terrestrial studies examined the effects of noise on birds. Several reasons probably attribute to this, including: their use of acoustic stimuli for communication, locating prey or predators, general public interest in birds, the dynamic lifestyle of many bird species, and status on the endangered species list. Also worthy to note as did Brown and Raghu (1998) that most of these studies were financially supported by military and transportation agencies.

Three long-term studies were reported during this time period. Delaney et al. (2002) investigated the effects of military operations including artillery noise, military vehicle and helicopter noise on Red-cockaded Woodpeckers (RCW). Pruitt et al. (2002) consolidated report describes the effects of military aircraft overflights on Peregrine Falcons. The third long term study also examines the effects of military aircraft noise, but on Mexican Spotted Owls (MSO). This study, as reported at this conference by Bowles et al. (2003), has not been completed and therefore conclusions will not be forthcoming for another couple years. These studies have several commonalities: all three species were on the endangered species list; all developed methods to accurately document the noise stimuli; they examined behavioral responses of the birds to various levels of stimuli to determine proximate effects; they examined demographic and nesting success data to assess populational effects; and they used various forms of technology to actually record responses to noise events. The United States (U.S.) Army addressed concerns of RCWs, since many of their installations have these birds on their restricted access military ranges. Weapon noise from .50 caliber blank machine gun fire and artillery simulators appears not to significantly limit RCW reproductive success (Delaney et al., 2002). Male Peregrine Falcons tended to respond more intensely to jet overflights than females. Pruitt et al. (2002) also reported that peregrines were more sensitive to humans and other raptors than to disturbances by helicopters, jets and boats. Their study indicated that intensity of response is a better indicator of productivity than noise exposure. Male peregrine ledge attendance was somewhat decreased at nests sites exposed to jet overflights, but was compensated for by increased attendance by females. Pruitt et al. (2002) concluded that there was no significant effect of exposure to jet overflight on peregrine nest success or productivity.

Brown et al. (1999) examined the effects of weapons-testing impulsive noise (ranging from 80-129 dBPeek) on Bald Eagles and found that the most common response at nests was no activity

(92.7%). At roosting sites, eagles no-activity response was somewhat less (72.7%). The greatest activity response in either case was head turning. Brown et al. (1999) found no significant difference with nesting success between eagles in the exposed areas versus the controlled.

Ward et al. (1999) exposed large flocks of geese to small fixed-wing aircraft and helicopters flying an array of altitudes and lateral distances to test their behavioral responses. Noise levels were categorized as high (>76 A-weighted decibels [dBA]) and low (<76dBA); altitudes ranged from 30-760 m; lateral distances were from zero to 2 km. Brant flocks exhibited flight responses to 75% of the overflights; Canada geese responded considerably less often. Ward et al. concluded that lateral distance was the most important parameter in predicting geese response to overflights. Helicopters seemed to elicit greater response than fixed-wing aircraft. Since waterfowl are known to respond to a variety of disturbances, Conomy et al. (1998) tested aircraft overflight effects on ducks. Contrary to Ward, Conomy's noise source was fighter aircraft with sound levels averaging 85 dBA and ranging from 80-109 dBA. Conomy found no strong relationship between disturbance events and number of responses of black ducks (2.6%), American Wigeon (6.4%), gadwall (3%), and green-winged teal (7%). Ward et al. (1999) detected some habituation and Conomy (1998) attributed lack of response possibly to this phenomenon.

There are many observers that claim helicopter noise to be more disturbing to animals than fixed-wing aircraft. Delaney et al. (1999) exposed MSO to helicopter and chain saw noise. They found that chain saw noise was more disturbing at equivalent distances and that beyond 105 m minimized their responses to stimuli. Giese and Riddle (1999) examined the response of emperor penguin chicks to helicopters in Antarctica. Chicks tended to be more vigilant and exhibited flipper-flapping when exposed to the helicopter overflight at 1000 m above the ground. Since the maximum sound level was 68.2 dBA, disturbance may have been influenced by the visual as well as the acoustic stimulus.

Terrestrial Animals - Mammals A significant number of studies of noise effects on terrestrial mammals occurred between 1989 and 1996. Since then, only a few studies have been performed on this class of animals. A considerable amount of research has been done on caribou due to the extremely harsh conditions in which they live. Most recently, Bradshaw et al. (1998) reported concern of petroleum exploration disturbing Wood Caribou in Alberta Canada. By estimating the energy costs of multiple noise disturbances, they concluded that there were occasions when sufficient numbers of disturbances exceeded levels that would cause winter mass loss in excess of 20%. Mass loss of this magnitude could impact the survival of individual caribou and the population.

Similar concerns exist for ungulates that live in the desert, another harsh environment. Krausman et al. (2001) monitored behavior of adult and fawn Sonoran Pronghorn exposed to military noise. Their conclusions were that aircraft noise and other anthropogenic stimuli did not abnormally disturb adult pronghorn behavior. They also noted that pronghorn seemed to habituate to the stimuli. Krausman also observed more movement of fawns to noise stimuli, but because there were so few observations, no conclusions could be made. Hearing tests were also performed on pronghorn and hearing was determined to be similar to that of mule deer and bighorn sheep and less acute than humans at most frequencies (Krausman 2001).

Terrestrial Animals - Reptiles Noise studies on reptiles have probably been neglected because they are not commonly thought of when dealing with sound issues. Though reptiles have auditory organs, early researchers believed that reptiles were insensitive to acoustic stimuli. Bowles et al. (1999) performed extensive studies on desert tortoises and the effects of aircraft noise and sonic booms. They were able to measure auditory thresholds averaging 34 dB (decibels) sound pressure level (SPL) at 250 Hz, the tortoise's most sensitive frequency. Exposing tortoises to multiple simulated aircraft noise at levels up to 114 dB C-Weighted sound equivalent level (CSEL), no significant temporary threshold shifts (TTS) were detected. The same was true when tortoises were exposed to two 6 pounds per square foot (psf) simulated sonic booms. During exposures to multiple simulated sonic booms. TTS ranging from 5-20 dB was observed in 56% of the experimental animals. Recovery times were less than one hour. Bowles also reported that tests for startle response were elicited after tortoises were touched, but not observed when exposed to aircraft noise or sonic booms. They reported that tortoises responded by freezing when startled, but quickly habituated to noise events. Bowles et al. (1999) did not observe physiological changes in response to acoustic stimuli.

Aquatic Animals - Marine Mammals With the increasing publicity of marine mammals and their response to noise, it is not surprising that the majority of studies on noise effects in the aquatic system have focused on them. The recent mass strandings in the Bahamas have pushed this topic into the spotlight. It is important to know which species will be affected by which frequencies and it is also important to know what noise levels impact each species. What has sufficed has been to attribute one animal's hearing abilities to other species. While there has been a lot of work documenting marine mammal behavioral responses to noise in the last five years, the focus here is on physiological responses (except temporary threshold shift which is reported at this conference by Mardi Hastings), use of acoustical harassment devices, and underwater noise modeling.

Wild animals are difficult enough to study and studying wild marine animals presents its own unique challenges. Studying them in the ocean often requires adding noise to the environment (via boat or airplane surveys), the animals are often difficult to follow, and responses are difficult to measure. Workshops were recently held by the European Cetacean Society to discuss the use of Controlled Exposure Experiments for studying noise effects on marine mammals. The science, methodology, policy, and political issues were all considered for this method for experimentally studying the effects of noise in the wild (Gordon et al., 2003). Tyack (2001) has developed a digital acoustic tag (DTAG) that will calibrated recordings of sound and the dive movements of the tagged whale. This method would allow the collection of data pre-, during, and post-exposure to man-made sounds. Several studies used the Method of Free Response (MFR) and trained behaviors to study odontocete hearing in captive bottlenose dolphins (*Tursiops truncatus*) and belugas (*Delphinapterus leucas*). The effects of underwater explosions on masked hearing thresholds (Finneran et al., 2000); masked hearing thresholds in relationship to changing pressure, velocity, and intensity thresholds (Finneran et al., 2002a); the effect sounds from a seismic watergun on hearing thresholds (Finneran et al., 2002b); and auditory filter shapes (Finneran et al., 2002c) were all studied using this method. In another captive study, jaw phones were successfully adapted to measure auditory sensitivity in captive bottlenose dolphins (Brill et al., 2001).

Monitoring physiological parameters in response to noise (e.g. heart rate, auditory response sensitivity, temporary and permanent threshold shift, masked hearing thresholds) are difficult to measure in wild marine animals. The studies of captive marine animals have advanced our understanding of their hearing, but to determine effects in the wild, different methods for evaluating effects need to be used. When quantitative measurements can be made of wild animals, the data is invaluable. The Concorde's sonic boom was shown to elevate the heart rate of six of the nine male harbor seals fitted with heart-rate monitoring units, however the four gray seal mothers and three pups showed no rate alteration as a result of the sound (Perry 2002). One noninvasive method for determining noise effects used differences in respiration rates as an indicator of a response to underwater noise for sperm whales (*Physeter macrocephalus*). In the presence of calves, mature females and immature individuals increased their blow-intervals when whale-watching boats were near (Magalhaes et al., 2002.)

Using sound to deter the presence of animals sometimes presents conflicting issues: is it helping the animal by alerting it to danger but yet adding more ocean noise, is it deterring some species but attracting others, is it deterring additional species other than the target, will the animals habituate to the noise? Terhune et al. (2002) found acoustic harassment devices (AHDs) not effective for deterring harbor seals from aquaculture farms in the Bay of Fundy. Since the sound would have to cover a large area, the loudness required at the cage would also be loud kilometers away and would impact additional animals. Cox et al. (2001) found pingers ineffective for deterring harbor porpoises (*Phocoena phocoena*) from mooring equipment because they eventually habituated to the sound. The porpoises also decreased their echolocation near the pingers, indicating they were not acting cautiously near them. AHDs tested on salmon farms in two locations in British Columbia intended to deter the presence of harbor seals (*Phoca vitualina*) actually reduced the presence of killer whales (*Orcinus orcas*) in one of the locations. Once the AHD was removed from the site, whale occurrence returned to normal indicating their presence had been altered due to the introduced noise (Morton and Symonds 2002). Johnston (2002) found AHDs designed to keep seals away from salmon farms in the Bay of Fundy also affected porpoise presence when the AHDs were active.

Significant advances have been made in the field of underwater noise modeling. Modeling the propagation of noise under different conditions (e.g. temperature, bathymetry, ocean substrate, wave patterns) using different types of noise (e.g. pulses, explosions, vessel traffic) is beneficial for developing guidelines to protect all marine species (Ocean Studies Board 2003). Erbe and Farmer (2000) developed a software program to calculate received noise levels as well as estimate impact thresholds for marine mammals. Received noise levels are determined for factors of depth and range from the source. This information is then used by the program to determine the impact on marine mammals' communication interference, disturbance, and hearing damage. Sonic boom penetration was modeled for a real ocean surface by Rochat and Sparrow (2001) to create more accurate impacts estimates on marine animals. In 2002, Erbe published results of another software program modeling noise from whale-watching boats that generates an impact assessment model on killer whales. Models like these can greatly advance the noise effects field by eliminating the need for testing on animals in many instances. It's also beneficial for developing guidelines for noise sources and for estimating their effects on a variety of species in a variety of environmental situations. Incorporating what we know about underwater sound propagation, marine species hearing, marine species communication, and marine species distributions will help build a clearer picture of the effects of noise on these animals.

Aquatic Animals - Fish Very few studies give insight on the noise effects on fish (Popper 1998), especially long-term effects. Wardle, et al. (2000) found demersal fish startle to air gun discharges, but there was no effect on schooling behavior or any other routine behavior. McCauley et al (2000) found a startle response to short-range air gun signals, faster swimming during trials, and habituation through time. Normal behaviour was expected after 14-30 minutes. With an approaching air gun, fish were found to move through the stages of increased swimming, moving to the lower portion of the cage, and moving to a "huddle" in the center of the cage. The study summarized that at some noise level, demersal fish would respond by forming tight schools and reducing their depth. Though long-term studies on the effects of noise have not been done, these short-term quantitative studies are beneficial. Knowing the effects on fish is important as they are vital members of the food chain and damage here can prove disastrous all through the ecosystem.

Aquatic Animals - Reptiles There is also very little data on aquatic reptile hearing and the effects of noise on them (Popper et al., 1998). A current study by the University of Maryland and the Office of Naval Research at the New England Aquarium is assessing hearing capabilities on a captive green sea turtle (*Cholonia mydas*). By using operant conditioning and positive reinforcement, they have been able to determine the individual hears tones from 100-500 Hz a well as the turtle's threshold for hearing those tones (Office of Naval research 2003). These results are preliminary and the old age of the turtle needs to be taken into account. Again, the trap presents itself for attributing the hearing abilities of an old individual to the entire species, or even further to all marine turtles. McCauley, et al. (2000) found caged green and loggerhead (*Caretta caretta*) sea turtles increased their swimming activity during air gun levels of 166 dB and acted erratically at 175 dB. The turtles were found to increase their amount of time swimming as the air gun level increased. They correlated the 166 dB and the 175 dB to startle and avoidance levels, accordingly, however, different bathymetry and substrates would alter these levels.

Discussion Research on the effects of noise on animals has made considerable progress. Before 1990, many studies documented animal behaviors but gave little attention to describing the acoustic stimuli. Since that time, researchers have taken more care to describe the noise stimuli and to ensure that their experiments are repeatable. There has also been progress in the last several years to understand the effects of noise on birds and marine mammals, but there is a major gap in studies focusing on both terrestrial and aquatic reptiles and fish. For appropriate guidelines and informed decisions to be made, these gaps need to be filled. Standards for noise exposures for one species do not necessarily convey to others. Assessing noise effects needs to take into account not only the species' hearing ability, but also the species' ability to escape the sound. Sessile or slow-moving animals may not be able to make the necessary change in location to adjust the received noise level. Further consideration must be given to the biological costs of avoiding sounds. Habituation to noise has also not been investigated to a great extent. Use of acoustic harassment devices will not work if the animal has investigated the sound and determined it is benign. Habituation benefits an individual by avoiding wasted energy expenditures on a repeated stimulus, but is there any consequences? Once a noise source has been deemed benign and the animals stay in the area, is it doing additional damage? A study by Muzet (1983) found that even after humans stop responding to a noise, their cardiovascular responses are still the same. Neither has it been established which species can habituate and which will not. Again the trap needs to be avoided of applying the habituation of one species to another, since they won't necessarily convey.

Keywords: Animals, noise, marine mammals, birds, fish, reptiles, animal behaviour, disturbance

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