AN OVERVIEW OF RESEARCH ON THE EFFECTS OF NOISE ON ANIMALS

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ABSTRACT: While there is recognition worldwide for the need to assess the influence of noise on animals, both in terms of ecological disturbance in the wild, and effects on stress or productivity of domesticated animals, limited research has been undertaken in these fields. The paper presents an overview of this research activity and the contexts in which it has been carried out. Much of the literature deals with the impact of military activities, seismic and other exploration activities, and transport. The paper identifies relevant Australian work in the field and identifies some limitation in current work and avenues for further research.

1. INTRODUCTION

The effects of noise on humans have long been recognised. In contrast, the effect of noise as a stressor for wildlife and for captive/domesticated animals has received far less attention [1]. Animals depend on acoustic stimuli for communication, navigation, mating and foraging functions. Research into the effects of noise on these functions, and the effects of noise on overall disturbance to the individual animal, the habitat and the ecosystem in which they reside, is important for wildlife management, for management of anthropofaunal conflict in areas such as tourism and aviation, and for sustaining or maximising animal productivity. Research into the effects of noise on animals has also been undertaken for the purpose of extrapolating the results to humans, particularly within a health context.

This brief article provides a sketch of the body of research activity in this field, illustrates the different categories of research undertaken, introduces the reader to the published Australian work in this field, and some work in progress.

Most of the work on noise and animals can be placed within the four broad research methodologies shown in Table1. These methodologies include studies based on field observations, and both field-based and laboratory-based experiments. Much of the literature reports research based on field observations, and while this has provided valuable insights, the absence of any control over the acoustic stimulus and little other than gross measures of response (for example, observing gross fly off, or observing "no visible response") means that these studies have little chance of replication. Field experiments, controlling the stimulus, and/ or making detailed measures of response, are extremely difficult to conduct, and this presumably explains their paucity in the literature. Laboratory experiments are far simpler, but of course raise questions of applicability of their results in the field, particularly given the complexity of the ecology of disturbance discussed below. The fourth category, in Table 1, while not measuring effect, provides critical baseline studies of natural acoustic environments in which organisms live and against which measures of intrusive human generated noise can be assessed. For example, Cato [2,3] has made significant contributions to the understanding of the acoustic characteristics of the marine habitat near Australian waters. His studies provide a setting within which biological effects of marine acoustical disturbance can be addressed.

Table 1. Research methodologies

RESEARCH METHODOLOGY	POTENTIAL EXPERIMENTAL TREATMENTS	MEASURES OF RESPONSES
Field observations	Usually nil, or presence/ absence of acoustic stimulus with no control of stimulus	field observations (e.g. gross fly off), anecdotal evidence
Field experiments	Controlled stimulus or uncontrolled stimulus	Observed behavioural response, but more recently physiological measures
Laboratory experiments	Generally controlled stimulus (sometimes uncontrolled stimulus)	Physiological measures (heart rate, blood pressure, catecholamine levels), behavioural response
Baseline acoustic studies	Not applicable	Not applicable

2. CONTEXT AND MANAGEMENT IMPLICATIONS

Research into the effects of noise on animals has been in two major contexts: animals in the wild, and captive/domestic animals. Table 2 indicates the scope and areas of management implication within each of these contexts, and cites representative research studies. The examples in Table 2 are by no means a comprehensive survey of the literature, but provide at least a starting point for readers interested in particular situations. Australian studies are indicated in Table 2.

Research on the effects of noise on wildlife (and to some extent on captive/ domestic animals) needs to be undertaken within a theoretical framework of the ecology of disturbance of animals as illustrated in Figure 1 [40]. This framework incorporates various existing ecological models for concepts

Table 2. Context and Management Implications

CONTEXT	SCOPE	AREAS OF MANAGEMENT IMPLICATIONS	EXAMPLES (REFERENCES)
Wild	Wildlife management & conservation	Tourism & ecotourism	Great Barrier Reef (Readhead [4]*; Hicks et al. [5]*) Off-road vehicles (Brattstrom & Bondello [6]) Aircraft noise (Kushlan [7], Brown [8]*, Stockwell & Bateman [9]; Gipson [10], Gabrielsen & Smith [11])
		Military activities	Military aircraft (Ellis et al.[12]; Russell [13]; Weisenberger et al [14]; Temple et al [15])
		Research activities	Antarctic and sub-Antarctic Islands (Rounsevell & Binns [16]*; Woods et al.[17]*)
		Mining and exploration	Seismic exploration (Gunn & Livingstone [18]; McCauley [19]*; Pearce [20]; Lane [21]*)
		Transport • Surface • Marine • Air • Pipelines, etc. Impact Assessment	Road traffic noise (Reijnen [22]; Reijnen & Foppen [23]; Reijnen et al.[24]; Reijnen et al.[25]) Marine exploration (Richardson et al.[26]) Aircraft noise (Dunnett [27])
	Urban wildlife management	Airports Roadways	Road traffic noise (Reijnen [22]; Reijnen & Foppen [23]; Reijnen et al.[24]; Reijnen et al.[25])
	Animal Scares	Protection of human safety Protection of primary produce Protection of buildings	Bird scares (Slater [28]; Bomford & O'Brien [29]*; Jaremovic [30]*; Nicholls [31]*; Bomford [32]*; Andelt et al.[33])
Captive/ Domestic	Production	Cattle	Milk production or pregnancy (Head [34]) Pregnancy (Henley & Rybak [35]; Gipson [10])
		Poultry	Egg production (Belanovskii & Omel' yanenko [36])
	Human/ Public Health	Physiological research	Auditory physiology (Kiernan & Cranney [37]; Robertson & Anderson [38])
		Urban stock	Effects of animal noise on human health in suburbia (Tickell [39]*)

*indicates research activity in Australia

such as tolerance range, niche, habitat and life-history strategies and provides a sound basis for the study of noise as ecological disturbance. Figure 1 summarises the complex means by which disturbance characteristics alter the existing environment of an organism and as a result the organisms' requirements are no longer met by the habitat. Not only must the dose of the acoustic stimulus be fully understood e.g. nature (type of noise – aircraft noise, etc.), intensity, spectral frequency, duration, frequency of occurrence (how often the target organism is exposed in a given amount of time), predictability, coexistence with another stimulus (eg visual stimuli), scale (range of exposure e.g. footprint of a sonic boom), timing (time of day), but so too must the organisms' characteristics e.g. tolerance level, physiological state, timing (in terms of life-history stage exposed), powers of dispersal and behaviour. Further, the critical measures of response to the noise disturbance include the individual's, colony's, and the species', chances of survival and reproduction as a result of the exposure to the hazard. It is vital to note that characteristics of the disturbance do not act independently of one another in producing an impact [40].

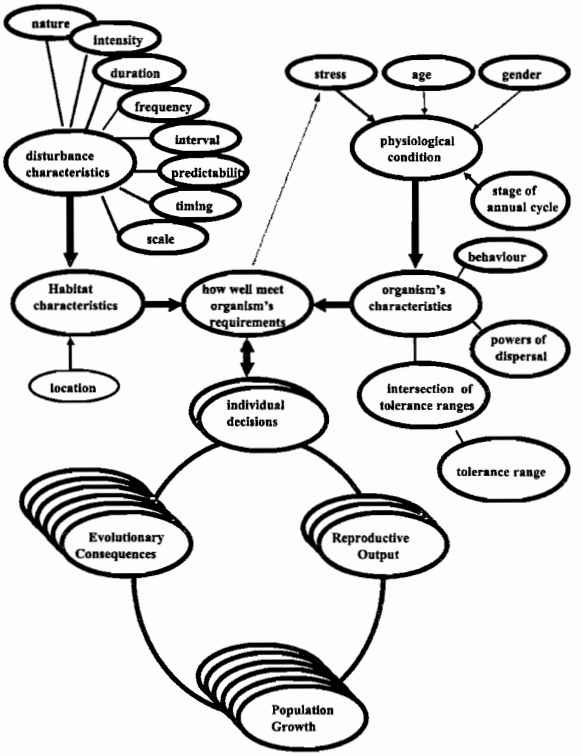

Fig 1. Theoretical framework of the ecology of disturbance [40]

3. AUSTRALIAN RESEARCH

The authors conducted a comprehensive search of published literature in preparing this paper – but the conclusion is that there is sparse Australian work in this field. Two published examples of field research, one marine (McCauley, 1994) and the other terrestrial (Brown, 1990), provide good examples of work contributing to an understanding of the significance of noise as ecological disturbance and these are summarised below. In addition to these examples of field research, brief reference is made to some Australian laboratory work on noise and its influence on animal physiology, and to some unpublished work and to work in progress.

The study by McCauley [19] was carried out as a review of the impact of oil and gas exploration, particularly seismic surveys and its implications for marine habitats. This study is interesting and such comprehensive investigations are rare in the literature. Various features of this study make it a significant contribution to this field of research. McCauley [19] provides a thorough documentation of the ambient noise in marine habitats of Australia comprising both biological (e.g. invertebrates, fish and marine mammals) and non-biological sources (e.g. marine transport noise, wind, rain and

earthquakes). In the context of the ecology of disturbance [40] these data provide a description of the acoustic habitat characteristics. He then reviews the potential disturbance characteristics, seismic survey sounds, and goes on to comprehensively document the characteristics of marine organisms and their various life-history strategies which make them more susceptible to impacts resulting from noise exposure, and reviews the pathological and behavioural effects of seismic exploration noise among the various taxa. McCauley [19] defines various zones of influence of marine acoustic disturbance that include audibility, masking, behavioural response, avoidance, pathological effects and lethal effects. A zone refers to the radius from a point source within which organisms exposed are susceptible to a certain effect. Under each of these zones he addresses the effects on various marine fauna and identifies existing gaps in the knowledge. He also ranks the significance providing a framework for the effects of noise as ecological disturbance, and presents the long term implications of seismic exploratory activity and a template to assess noise effects in marine habitats.

The study by Brown [8] was carried out to assess potential impact of aircraft noise on seabirds. Almost all studies prior to Brown [8] were undertaken on birds that had prior exposure, thereby introducing the potential issue of habituation to noise stimuli. Furthermore a majority of these studies used stimuli that were either partially controlled [5, 27, 41] or used only gross measure of response to assess the impacts of such stimuli [5, 7, 18].

Table 3. Experimental design and results. Brown [8]

STUDY COMPONENT	NOTES
Study site	Eagle Cay (Cairns-Cormorant Pass section of the Great Barrier Reef Marine Park)
Target species	Crested tern (Sterna bergii); one large and one small colony
Acoustic stimulus (Disturbance characteristics)	Nature: recordings of aircraft noise at cruising speed (100 knots) at altitudes ranging from 1000 to 250 feet Intensity: Amplitudes of the flight signatures conditioned to devise seven treatments with peak fly-over levels of 65 dB(A) to 95 dB(A), at 5dB intervals Duration: 30-35 seconds Scale: the scale of exposure controlled by controlling the position of speakers to ensure that the radiation patterns establish a uniform sound field over the target group of birds. The birds were exposed to all seven treatments with 10 min intervals between them, for four days.
Ambient noise (Habitat characteristics)	Wave action (55 to 65 dB(A)) Bird Calls (60 to 75 dB (A)) (bird call activity unrelated to the experiment observed to exceed those due to wave action)
Potential behavioural response (Organisms' characteristics)	Scanning, alert, startle/ avoidance and escape, in ascending order of behavioural responses, recorded on film 20 seconds prior to peak exposure and 25 seconds after peak levels. All observations were recorded on film. The response of each bird in the target group was scored separately. (Note: The birds exhibit this range of behaviours even without exposure to the stimulus and there a control segment of 45 seconds without any stimulus was also recorded. Only those behavioural responses directly attributable to the stimulus were recorded.)
Results	Proportion of individuals responding with a higher order behavioural response to exposure increased with the level of noise exposure.

Research by Brown [9] provides a baseline study on influence of aircraft noise on a seabird colony that had no prior exposure. Care was taken to present a controlled, but variable, stimulus to test for habituation effects, and to measure a range of behavioural responses. Details of the study are summarised in Table 3.

This study brought to light key factors that further research in this field must observe:

a) The acoustical stimulus to which the organism is exposed has to be controlled/ measured.

b) Observations of response have to be recorded on film to capture a hierarchy of responses (direct measures of physiological response, for which equipment is now available, would be preferred)

c) Baseline information on previously undisturbed individuals or colonies is required to ascertain the significance of habituation to noise exposure.

d) Research needs to be directed at ascertaining the ecological consequences of animal exposure.

Other Australian work [29, 30, 31, 32] has been directed at the use of sound to scare wild animals away from primary production activities. This is part of a considerable body of worldwide literature [28, 33] on this commercially relevant topic. The work is directed primarily at birds feeding on agriculture and aquaculture produce.

The Human Impact Research Program, within the Australian Antarctic Division, currently has work in progress to quantify the effect of helicopter noise on Antarctic wildlife (M. Giese pers.com). The experimental work has been conducted over two field seasons with wildlife responses measured by videotaping changes in animal behaviour and by utilising a range of physiological monitors.

The reviewed literature also included reports of a wildlife incident on an Australian sub-Antarctic islands which could relate to an aircraft noise stimulus. Rounsevell and Binns [16] and Woods et al [17] reported the discovery of approximately 7000 dead penguins at Lusitania Bay, Macquarie Island in 1990. The mass deaths in this breeding colony of king penguins (Aptenodytes patagonicus) was a result of asphyxiation probably resulting from a stampede. These authors listed potential causes of the stampede to be harassment by natural enemies, seismic activities, unusual weather events or anthropogenic disturbance. However, the overflight of an aircraft flying to the Australian National Antarctic Research Expeditions station, which was known to have occurred before the discovery of the stampede deaths, was speculated to be the most likely cause of this event. As these reports were based entirely on field observations after the discovery of the dead birds, and after post mortem examination, it must be emphasised that the cause of disturbance must remain speculative. However, the authors still advise caution in allowing aircraft to approach breeding colonies that have had no prior exposure.

There has been some Australian laboratory work. Kiernan and Cranney [37] examined the influence of an immediate-

startle stimulus on the freezing response in Wistar rats under laboratory conditions. They found that a controlled startle-stimulus of 117dB (SPL, 20mPa) amidst a background of white noise (70dB SPL, 20mPa) for 60s failed to elicit freezing responses. Robertson and Anderson [38] examined the cochlear modulation of the deafening effects of loud sound in guinea pigs. The objective of this study was to provide an understanding of cross cochlear pathways in hearing physiology and a subsequent extrapolation of the results to physiological effects of noise on human hearing. Within the theoretical framework of disturbance, these studies address the effect of a hazard out of the context of the target organisms' habitat. However, they potentially provide insight into tolerance levels and behavioural responses to acoustic stimuli and into potential response in the wild, though this was not the immediate objective of the studies.

4. CONCLUSIONS

The review of the literature indicates that Australian work in this area is sparse and sporadic (though close examination of the references cited by McCauley [19] suggests that there is considerable information available in unpublished documents and government reports). Much of the literature deals with the impact of military activities, seismic and other exploration activities and the influence of transport noise. Influence of noise on the effect of terrestrial animals is relatively unexplored. A study is required for terrestrial habitats, dealing with ambient noise levels and acoustic characteristics of terrestrial fauna and potential responses to acoustic disturbance. However, the smaller areas of terrestrial habitats, and the limited distribution of previously undisturbed regions, makes such baseline studies difficult.

Difficulties in replication of research into effects of noise on animals is accentuated by the use of uncontrolled stimuli and the measurement of gross responses. Though such studies are useful as pilots, critical examination of a particular response to a pre-defined stimulus is vital for future noise management. Internationally, very few studies in this field have designed experiments with a level of precision that can identify a threshold stimulus above which the target animal is likely to experience detrimental effects. Habituation to noise could enable animals to increase tolerance but, as with humans, anecdotal evidence of habituation is inadequate, and will need to be proven by appropriate studies. The influence of habituation, and overall tolerance to acoustic disturbance, are areas that require further investigation.

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