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MEASURING THE EFFECT OF AIRCRAFT NOISE ON SEA BIRDS

A. L. Brown
School of Australian Environmental Studies, Griffith University, Nathan, Brisbane, 4111 Australia

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This paper reports on a procedure which exposes sea birds to acoustic stimuli simulating aircraft overflights, and is one of the first experiments to attempt to quantify the responses of birds in the wild to noise. The experiment, conducted on Australia's Great Barrier Reef, involved presentation of pre-recorded aircraft noise, with peak overflight levels of 65 dB(A) to 95 dB(A), to nesting sea bird colonies. Sea bird responses were videotaped and these tapes were subsequently analysed by scoring the behavioural response of each bird in the colony. Results of a trial of this experimental procedure for one species, the Crested Tern (*Sterna bergii*), indicate that the maximum responses observed, preparing to fly or flying off, were restricted to exposures greater than 85 dB(A). A scanning behaviour involving head-turning was the minimum response, and this, or a more intense response, was observed in nearly all birds at all levels of exposure. However an intermediate response, an alert behaviour, demonstrated a strong positive relationship with increasing exposure. While the experiment has provided good control on simulated aircraft noise levels, preliminary observations of response of the colonies to balloon overflights suggests that visual stimulus is likely to be an important component of aircraft noise disturbance.

INTRODUCTION

There have been no definitive studies on the effects of subsonic aircraft noise on birds, and, in particular, there is limited information on the effects of aircraft noise on wild bird populations.

Several features characterize previous investigations of bird response to aircraft overflights. Most have been based on observation of response with no or limited control over the acoustic stimulus (Dunnett 1977; Burger 1981; Hicks et al. 1987). Measurement of the responses has been primarily visual at the time of the disturbance, but videotaped recordings have occasionally been used. Further, only gross disturbance responses have been measured, namely flushing or locality avoidance (Hicks et al. 1987; USDOI 1969; Gunn and Livingstone 1972; Kushlan 1979) though a hierarchy of responses was defined by Windsor (1977) in his investigation of peregrine falcons affected by aircraft. However, the latter involved observation of nesting pairs only, not the more difficult task of observing a larger colony. Various studies have also recognized the possibility that the bird populations under investigation may already have been habituated to aircraft noise (Grubb 1978).

Three principles were developed from this prior work to be the basis of new experimentation. Firstly, the acoustic stimuli to which the colony was to be exposed had to be carefully controlled. Secondly, observations of bird response to the stimulus had to be recorded on film to enable measurement of responses more subtle than flushing. Finally, initial experimentation had to be on a colony with no prior exposure to aircraft disturbance. Habituation to aircraft noise exposure may be an important phenomenon, but it cannot be investigated without first establishing a baseline of the response of unhabituated colonies to noise exposure.

STUDY SITE

The study site was Eagle Cay in the Cairns-Cormorant Pass section of the Great Barrier Reef Marine Park. Colonies on this cay had no chronic exposure to aircraft overflights or to other forms of human disturbance. The species selected for initial study was the Crested Tern (*Sterna bergii*). It is a colonial nester, found mainly in open habitat among low grasses and herbaceous vegetation, and breeds in large numbers, up to several thousands, in the summer months. The eggs are laid on the bare ground in hollow scrapes (Langham and Hulsman 1985). Because it nests in open areas, this species could be filmed relatively easily, allowing detailed measurement of the behaviour of individual birds in a colony.

The experiment was partitioned between two colonies. Colony 1 was small and isolated with up to 29 birds present at any one time. This colony was in the last days of the incubation period and several chicks hatched towards the end of the experiment. Colony 2 consisted of several thousand birds, of which only a portion on the periphery, up to 59 birds present at any one time, was observed. This colony was in the middle to late stage of the incubation period. While it was considered possible that size of colony and stage of the breeding cycle could effect response, subsequent analysis showed that responses did not vary across the two colonies and the pooled results are reported in this paper. Hides were established in a 25 m-distance from the edge of the colonies. They provided shelter for two research staff members and were the locations from which the acoustic stimulus was controlled and bird behaviour filmed.

THE NOISE EXPOSURES

Instrumentation quality mono tape recordings of the overflight of a DHC-2 Beaver floatplane had been recorded on a different island. The recordings were of the aircraft operating at cruise speed (100 knots) and at altitudes ranging from 1000 ft to 250 ft. (300 m to 75 m). Selections from these overflight signatures had their amplitude conditioned in the laboratory to provide seven treatments with peak fly-over levels at 5 dB intervals from 65 dB(A) to 95 dB(A). The duration of each treatment was standardized at 30 to 35 seconds. A-weighted time histories of the seven treatments are shown in Fig. 1. It can be noted that the overflight treatments did not have an identical signature as the more intense levels, generated by lower altitude aircraft, have steep onset and decay of the signal. By contrast, the lowest peak levels are generated by higher altitude aircraft with a characteristic rounded peak. The treatments have been described by A-weighted levels, not because of any relevance of this weighting to bird response, but because this is the standard measure of noise of general aviation aircraft and that which would likely be specified in any future management guidelines.

In the field these recordings were amplified and replayed, unfiltered, through a column loudspeaker positioned 1 m above the ground. Prior extensive testing of the radiation patterns from the speaker had established that a uniform sound field (± 1.5 dB) of the required sound intensity could be obtained over a ground area 6 m wide by 3 m deep located 8 m from the speakers. Colony 1, being small and isolated from other colonies, was completely contained within this uniform sound field. For the larger colony a selection of birds on the periphery was marked out and the speaker positioned to provide a uniform stimulus over this sub-group. No birds were located between the speaker and the birds under study. While the remainder of the colony was also exposed to the flyover noise from the speaker, the sound levels experienced by these birds were either equal to, or less

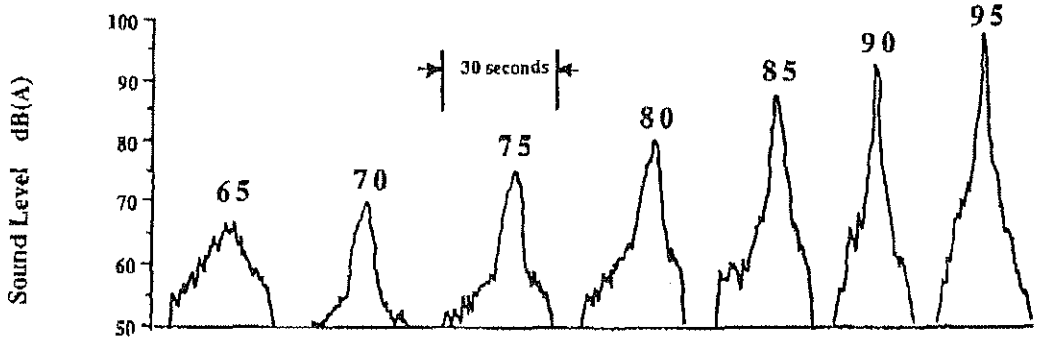

Fig. 1. Simulated aircraft overflight signatures of each of the seven acoustic treatments presented as stimuli in the experiment. Treatments are referred to by their peak A-weighted sound levels and are in 5 dB increments from 65 dB(A) to 95 dB(A).

than, the levels to which the observed sub-group was exposed. There clearly could be interaction effects between birds in different parts of the colony, but the reasonable assumption is made here that the response of the birds under observation would have been determined by their higher noise exposure, not by a sympathetic response to other birds in the colony responding to a lower level of exposure. A microphone located in the colonies monitored the level of every simulated overflight to confirm that the correct treatment level had been delivered.

The noise stimulus exhibited the typical frequency spectrum of general aviation propeller aircraft, with propeller-generated frequencies dominant below 500 Hz. Fig. 2 shows the spectrum at peak flyover level of the signal used for the 85, 90 and 95 dB(A) treatments. The spectrum of the lower noise level treatments was similar, but with some reduction of the frequencies above 1 kHz resulting from air absorption during recording of the higher altitude flights. The hearing range of Crested Tern is not known, but the range of its calls is from just under 1 kHz to 7 kHz (Cramp 1985) and it is likely that all except perhaps the lower propeller frequencies would have been audible to the species.

In the experiment the aircraft overflight signals would have been heard against a background of bird calls from within the colony and the sound of wave action on the shores of the cay. Both were highly variable, with wave noise depending on wind speed and generally in a 55 to 65 dB(A) range and with bird calls peaking at 60 to 75 dB(A). Bird call activity, unrelated to the experiment, was sufficiently intense at times to set the background levels in the colony above those due to wave action.

EXPERIMENTAL DESIGN

The smaller colony was exposed to all seven noise treatments and a control each day for four days. The larger colony was then subject to experimentation in the same way. The order of presentation of the treatments was randomized across the eight days using an extra-period latin square design involving eight treatments with nine replications of each treatment. The interval between each treatment was arbitrarily set at 10 minutes since earlier observation indicated that this species settled from a noise exposure well within this period. Equipment failure resulted in the loss of data for seven treatments (2 of 65 dB(A), 2 of 70 dB(A), 3 of 80 dB(A), 1 of 85 dB(A)).

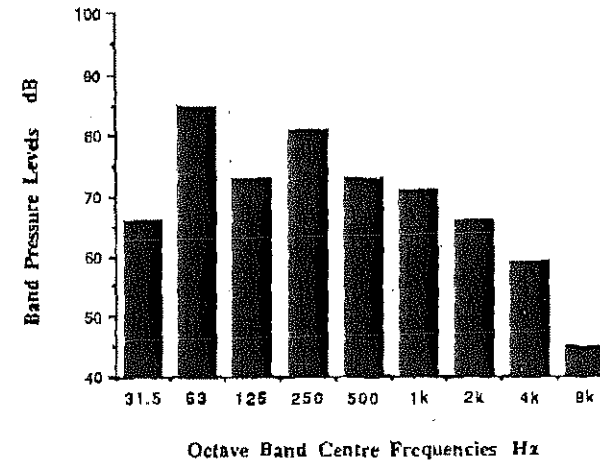

Fig. 2. Frequency spectrum of the aircraft noise stimulus used in the experiment.

OBSERVATION OF RESPONSES

Bird behaviour during each noise treatment was filmed on videotape, and segments of videotape, standardized to 20 seconds before the peak to 25 seconds after the peak, were used to score bird behaviour. A control segment of 45 seconds without any noise exposure was also filmed each day, and for this control all experimental procedures were carried out including powering the speaker system. These segments were analysed in the laboratory by repeated replay, with the behaviour of a single bird observed over the length of the segment. The maximum response behaviour of this bird was scored and the segment then replayed to observe the next bird. The following hierarchy of responses was adopted:

Scanning behaviour

This involved head turning. The head was more extended than in repose and was turned quite rapidly or dramatically in a horizontal plane. The head may have been cocked slightly to the side giving the impression of "looking up".

Alert behaviour

This was characterized by one or more of the following movements: the neck was fully extended; the carriage was more erect/tense; the bird may have re-oriented by either standing or moving the carriage unidirectionally or side to side; the bird may have taken a few steps on the spot with some wing tensing.

Startle/avoidance behaviour

This was an incomplete intention movement to fly up or escape. The bird may either have raised and flapped its wings momentarily whilst standing on the spot or moved off a short distance from the nest before returning. Eggs or chicks may have been exposed momentarily.

Escape behaviour

This involved flying up. Birds may either have flown a short distance away or wheeled out over beach and reef flat before returning to the nest emitting raucous alarm/distress calls. The nest was exposed for a longer time.

It should be noted that these behaviours can also result, not just from noise exposure, but from routine interactions with other birds in the colony and also from the presence of predators. Behaviours which could clearly be attributed to such interactions were discarded and only those behaviours which could not be attributed to such causes were used in this analysis. If responses which could be attributed to interaction were observed before another which could not be attributed to interaction or predators, a conservative approach was adopted by excluding the latter from the analysis. To minimize observer bias, behaviours were scored with no sound from the videoplayer, hence no acoustic cue as to when response attributable to noise exposure may have occurred.

PILOT STUDY RESULTS

An initial analysis of the latin square design used the GLM procedure of the SAS System (SAS Institute Inc. 1987) with the noise exposure treatments, the daily order within the eight-day experiment (DAY) and the sequential position of the treatment within each day's experiment (SEQUENCE) as effects in the design. Three separate sets of analyses were performed using, as dependent variables, the proportion of birds exhibiting a scanning or greater response, the proportion exhibiting an alert or greater response and the proportion exhibiting a startle or greater response respectively. As only small numbers of birds exhibited escape behaviours, no separate analysis was conducted on these responses though they are, of course, included in the variables defined above. (Means of the proportions of birds exhibiting an escape behaviour are plotted as a broken line in Fig. 3). Responses lost through equipment failure were estimated by the least squares method within the GLM procedure.

Parallel analyses were also conducted in which the arcsin transformation of the dependent variables were used. Such transformations are justified where the dependent variable is a proportion (Zar 1984). These transformations made only minor differences to the results and are reported below only where differences did occur.

DAY and SEQUENCE were included as effects in the design because bird behaviour observed in the experiment could include habituation (or sensitization) components caused by the cumulative effect of sequential application of noise exposures throughout a day and by the continuation of the experiment over successive days. In fact, the proportion of birds observed in each of the three response categories was found to be independent of both DAY and SEQUENCE ($p > 0.05$) and it must be concluded that bird responses to the simulated aircraft noise were not conditioned by the course of the experimentation. Further analysis also showed that responses were not influenced either by the level of the treatment immediately before, or two before, the current treatment. These are important findings as they indicate that short to medium term habituation/sensitization (within one day, and over successive days up to four days) does not occur in the observed responses—at least not with the stimulus provided in this experiment.

A different result did emerge using the arcsin transform of the proportion of the colonies exhibiting a scanning or greater response. Responses did depend on DAY, though subsequent examination of the mean responses across the eight days showed that the significant difference was confined to a single day of lower responses (Day 3). While no explanation has been found for this particular result, it is a salutary reminder of the need to carry out such exploratory experiments over more than one day, even if systematic habituation/sensitization effects are known to be absent.

With habituation/sensitization resulting from the experimental procedure itself discounted as a source of variation in each of the three response categories, bird response was found to depend clearly on the level of simulated aircraft noise. Fig. 3 shows the mean responses across the colonies to each of the noise treatments (mean of nine replications) and their 95% confidence intervals.

Few birds exhibited any of the response behaviours at the control treatments. The proportion of birds in the colony exhibiting a scanning or greater response was significantly higher at all levels of noise exposure than for the control ($p < 0.05$) and a reasonable

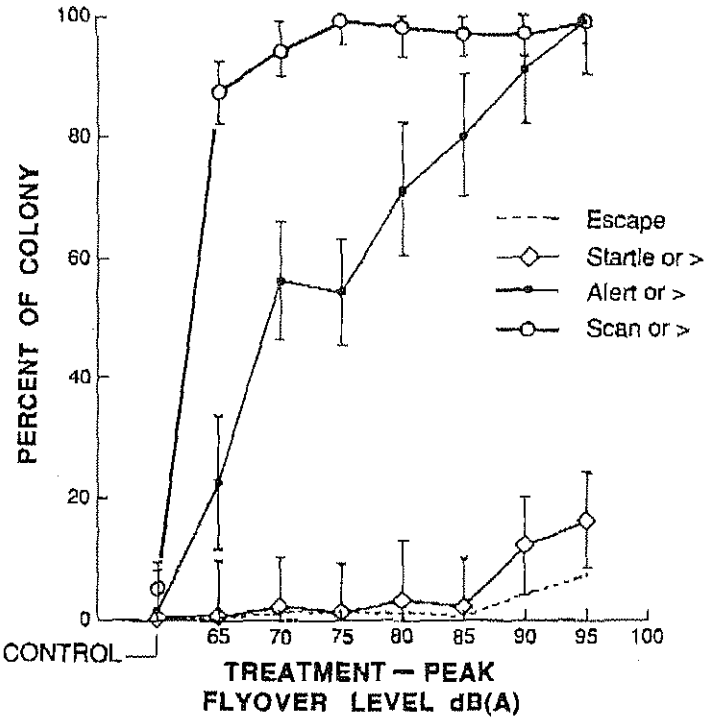

Fig. 3. Mean proportions of the Crested Tern colonies exhibiting different behavioural responses to the aircraft noise stimuli.

interpretation is that, at any simulated aircraft noise level which can be perceived above the background, most of the colony attempted to locate or evaluate the stimulus. Similarly, at all levels of noise, the proportion of the colony exhibiting an alert or greater response was significantly higher than for the control, and Fig. 3 shows that this proportion increased strongly with increasing noise level. Startle or escape behaviours were exhibited only at the higher noise exposures (responses at levels of 90 and 95 dB(A) were significantly greater than for the control) and by only a relatively small proportion of the colony.

In the field, measurements were also made of various environmental and bird colony conditions which might have influenced response. Weather conditions at the time of the treatment, the time of day (TIME), the state of tide (TIDE), and two measures of the behavioural state of the colony immediately prior to the application of each treatment were included in the analyses as potential covariates. The behavioural state of the colony was measured by the proportion of birds observed to be neither still nor exhibiting 'unhurried' movements (AGITATED) and the proportion exhibiting panting or gular flutter (PANT). The latter is a sign of heat stress (Dawson 1976). Analysis of these covariates did not yield unambiguous results. TIME of day of the treatment was a significant covariate ($p < 0.05$) in the analysis of the scanning or greater behaviour, but only when measures of the prior state of the colonies (AGITATED and PANT) or state of the TIDE were included in the analysis. For the alert or greater response, the proportion of birds exhibiting panting (PANT) was a significant covariate, but only when AGITATED was also included in the analysis. For the transformed responses the only relationship observed was between the startle or greater response and TIME (but only when TIDE was also included in the analysis). These covariates are clearly interwoven: high temperatures which cause panting clearly depend on time of day; state of tide does also; and presumably the prior level of activity in the colony may be related to feeding activity which itself depends on both time and tide (Hulsman et al. 1989). One can postulate reasons why any or all of these factors could influence colony response to an aircraft noise stimulus, but, while the present study indicates that such effects may exist, it is not able to unravel them. It should be noted however that their influence is small relative to the design factor of level of noise exposure.

DISCUSSION

Careful control over the stimulus is a prerequisite for studies investigating the response of wildlife to aircraft noise. This experiment has demonstrated that simulation can provide the tool by which precise and

replicable aircraft noise exposures can be applied to wild populations, avoiding the logistic difficulties and expense associated with aircraft overflights and, of utmost importance, providing the opportunity to avoid disturbance to most of the population under study and to other resident populations. This ethical consideration must be paramount where manipulative experimentation is the only means by which important management information on wild populations can be obtained. The current data set show that short term habituation/sensitization effects in the experiment are insignificant, allowing simpler experimental designs to be used in the future to determine dose-response relationships.

The observation procedures adopted in this study demonstrate that effects of a noise stimulus on nesting seabirds involve far more subtle behaviours than flushing and that these behaviours can be observed at levels of noise exposure only marginally above the background noise levels of wave action and bird calls. Clear trends have emerged relating noise exposure to observable behaviour. However, there is insufficient information on these behaviours, as yet, on which to attempt assessment of their ecological implications. Gross disturbance resulting in escape behaviour, observed at the higher noise exposures, is quite likely to effect breeding success through processes such as gull predation of eggs. But a more difficult question is whether repeated exposure to lower levels which result in alert and scanning behaviours does also. Fletcher (1988) notes that a series of investigations on the effects of low level jet and helicopter overflights on domestic animals in West Germany clearly identify physiological changes which indicate that aircraft noise exposure may well constitute stress to the animal. Management criteria should preferably be based on knowledge of the ecological implications of disturbance, but where non-disturbance to wild populations is critical, interim guidelines based on limiting any observable response to disturbance may be justified. There is a need to develop the experimental procedures further to examine the combined effects of visual and acoustical stimuli and to test the responses of other species. For example, some trials of free balloon flights over the colonies subsequent to the acoustic experimentation indicated that there may be additional, or interactive, effects from the visual stimulus. The mean percentage of birds exhibiting a startle or escape response to these flights was 98% in one colony, but 10% in the second colony. While the difference between the colonies cannot be explained at this stage, though possibly due to different distances from the colonies to the respective balloon release points as determined by suitable screening vegetation, the important point is that response to the visual stimulus of an aircraft overflight cannot be ignored and may prove to be the primary determinant of bird response. Further, in brief acoustic stimulus trials on another seabird species, Bridled Tern (*Sterna anaethetus*), escape behaviours were observed at much lower noise exposures than were observed for Crested Tern.

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