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Multivariate behavioural response of harlequin ducks to aircraft disturbance in Labrador

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SUMMARY

The effects of low-level aircraft over-flights on behaviour of harlequin ducks (*Histrionicus histrionicus*) breeding in central Labrador were quantified during 2000–2002. The Canadian Department of National Defence supports a low-level training programme in the 130 000 km^2 Military Training Area of Labrador involving military jets. The Institute for Environmental Monitoring and Research (IEMR) undertakes scientific research into environmental impacts of low-level military jet over-flights. A suite of 17 behavioural categories of paired male and female harlequin ducks was modelled, and a canonical variable representing alert behaviour, inactivity on the water and decreased inactivity out of water in response to over-flights represented 73.1% of the variance in the data cluster and provided marked separation of disturbed and undisturbed groups. Behavioural responses of harlequin ducks to military jets were 23 times stronger than their responses to floatplanes, helicopters and military cargo planes, and the significant interaction of aircraft type and noise indicated that noise may be the primary stressor affecting behaviour. A quadratic response of the canonical variable to noise generated from aircraft during standardized 30-minute observation periods was defined. The multivariate analyses were more robust because they indicated covariance in behavioural categories associated with disturbance that was not originally detected in univariate analyses, suggesting the importance of integrating behaviours other than overt responses. The significant effects of military jet over-flights on harlequin duck behaviour emphasize the need to evaluate potential population consequences of aircraft disturbance.

Keywords: behavioural response, canonical variable, covariance, dose-response, jet aircraft noise, multivariate analyses

INTRODUCTION

Through behaviour, an animal may avoid a disturbance (for example by flying away) or habituate if a stimulus is perceived as harmless (Korn & Moyer 1966). Studies of responses of animals to aircraft have generally involved classifying observed behaviour into categories from non-response to startle (Brown 1990). The behaviour of an animal is affected simultaneously by many biotic (and abiotic) factors, and there is synergism and feedback among different kinds of responses to a stressor. This multiplicity and interaction make it difficult to analyse ecological systems especially in univariate statistical designs. Univariate methods are extremely powerful in situations where the response of a single variable is of sole interest (such as demonstration of dose-response) and other factors can be controlled.

In ecological research, it is more often the case that the question at hand can be answered only by considering a number of variables interacting simultaneously. Hence the emphasis is on sets of variables rather than individual variables (McGarigal *et al.* 2000). I considered that the noise resulting from aircraft over-flights in Labrador affected many different, but partially correlated aspects of the behaviour of breeding harlequin ducks (*Histrionicus histrionicus*). These pieces of information need to be combined into a single best description of response through multivariate statistical analyses.

Noise is the primary stressor affecting wildlife during aircraft over-flights (Brown 1990, 2001*b*; Ward *et al.* 2001), and adverse outcomes in harlequin ducks increased with corresponding increases in the level of exposure (Goudie & Jones 2004). Aircraft noise differs with aircraft type, and typically there is a threshold level beyond which response increases markedly (Pater 2001), response varies among species (Ryals *et al.* 1999), and consequently birds may respond differently to different situations and aircraft types (Grubb & Bowerman 1997). Fixed wing and rotary blade aircraft types generate high amplitude noise but are anticipatory (i.e. have a gradual onset) in nature compared to noise from military jets, which is very high in amplitude and is sudden in onset (Pigeon 2001).

Goudie and Jones (2004) demonstrated effects of military jet noise on behaviour of harlequin ducks using a Before-After-Control-Impact study design. In this paper, I focus on refining the understanding of behavioural responses within the 30-minute watch period when over-flights occurred at Fig River, Labrador (53°03′N, 63°09′W). I assess the inter-relationship of behaviours as a collective response to being disturbed by low-flying aircraft. The analyses focus primarily on military jets, but also include low numbers of single (turbo) prop floatplanes and rotary-blade helicopters. I compare these data to the same behaviours without disturbance, because previous

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analyses focused on overt responses using single behaviours (Goudie & Jones 2004).

Harlequin ducks (*Histrionicus histrionicus*) are small sea ducks that inhabit fast-moving rivers and streams during the breeding season (Robertson & Goudie 1999), and their populations are sensitive to relatively small changes in adult survival (Goudie *et al.* 1994). The eastern North American population of harlequin ducks that breed throughout central Labrador was listed as endangered in 1990, and down-listed to a species of concern in 2001 (URL http://www.sararegistry.gc.ca).

The Canadian Department of National Defence (DND) supports a low-level training programme involving military jets in a Military Training Area (MTA) encompassing about 130 000 km^2 of central and southern Labrador. Following an environmental impact statement (EIS), management actions by DND are to be adjusted based on scientific research. Military jets frequently follow river valleys during low-level sorties (30–150 m above ground level) at speeds of 780–890 km h^{-1}, generating loud noise exceeding 100 dBA (DND 1994; Pigeon 2001).

My study addressed the following questions: (1) were there multiple behaviours (covariance) involved in responses to disturbances; (2) were there relationships between behavioural responses and dose of aircraft noise; and (3) were there differences in response related to aircraft type?

Table 1 General categories used to summarize behaviours of harlequin ducks. Behaviours were segregated into those on the water and those also recorded out of the water (indicated ho) for a total of 17 types.

Behaviour	*Description*
Agonism (ho)	Aggressive interactions among harlequin ducks, including chasing and sometimes fighting with conspecifics
Courtship	All courtship behaviour (on the water), for example inciting, prone, copulation
Feed	All aspects of obtaining food, including dip, dive, submerged, pause or glean
Peer	Looking into water (may be associated with food seeking)
Locomotion (ho)	All types of movements, for example swim, scoot, fly or walk
Preen (ho)	Feather maintenance using the bill as well as flapping and shaking
Inactive (ho)	Inactivity, including possible resting, sleeping and head down
Social (ho)	Directed calls and head nods
Vigilant (ho)	Maintaining a look-out (vigil), usually while the mate feeds or sleeps
Alert (ho)	Head stretched upward, body erect/tense, re-orientation and agitation, often accompanied with locomotion. Includes startle responses such as splash dive and panic flush

METHODS

Behaviour

Field personnel observed and quantified behaviour of breeding pairs of harlequin ducks during mid-May to mid-June of 2001 and 2002. A focal-individual sampling approach (Altmann 1974) was applied and linked to known individuals, because most harlequin ducks at Fig River ($n = 95$) were individually marked from 1999 to 2002 with field-readable coloured plastic leg bands.

Behaviour of harlequin ducks was characterized during bouts or states (such as feeding and resting; see Martin & Bateson 1986). For standardized watches, focal birds were monitored for 30 minutes (or until lost from sight) using binoculars and/or (20×–60×) spotting scopes. Instantaneous behavioural classifications of focal birds were recorded every 15 seconds, using digital watches with countdown-return beeper functions, from a suite of 17 general behavioural categories (Table 1). To minimize the chance that individuals were observed more than once and to maximize the independence of our data, a new individually colour-marked bird was selected for observation, or observers changed location to find new birds after each 30-minute observation period was completed.

Since instantaneous data recorded every 15 seconds were not statistically independent within each 30-minute watch, frequencies of behavioural categories were summed over each watch; each behavioural watch contributed one data record representing the sums of the frequencies of the each recorded behaviours (Martin & Bateson 1986). These frequencies were converted to proportions for use in the multivariate analyses. I re-titled the behaviour 'rest', as presented in Goudie and Jones (2004) to 'inactivity', because the lack of observable motile behaviours did not necessarily mean that they were resting *per se*. Virtually all female harlequin ducks present on the study area were paired, and there were slightly more males than females.

Sound and noise data

A detailed description of methods used for collecting sound and noise data are presented in Goudie and Jones (2004). In this paper, I use the parameter L_{max} which represents the maximum sound pressure level (as A-weighted decibels) measured over the sampled period (Larson Davis Laboratories 1997). For aircraft, this represented the highest L_{max} recorded during over-flight events, and for undisturbed situations it represented the highest recorded L_{max} during behavioural watches.

Statistical analyses

I used the general linear model (GLM) approach (SAS Institute Inc. 1999). Because the sample sizes were much larger, known individuals were sampled many times over each year. Therefore, I included model terms for the known individuals that were nested within disturbed and undisturbed categories for female and male harlequin ducks. For example the GLM statement to assess effect of aircraft noise and type on behaviour was:

$$\text{Behaviour} = \text{Group (who)} + \text{noise}^2 + \text{ aircraft type} \\ + (\text{noise}^2 \times \text{ aircraft type}).$$

This effectively controlled for variance associated with individuals, increased the degrees of freedom in the numerator and reduced the sum of squares in the error term, thereby reducing the potential for a type 1 error.

My statistical models encompassed response variables with categories (undisturbed male and female, disturbed male and female) in relation to the proportion of time spent in the 17 defined behavioural categories, and were therefore appropriate for the application of multivariate analysis of variance (MANOVA), which maximizes the ratio of among-group to within-group variance in canonical scores. Subsequent to a statistically significant MANOVA, a discriminant analysis (DA) was applied. It is logical to consider DA as an extension of MANOVA, because overall I was interested in testing the null hypothesis that the groups did not differ. Once differences were detected I used DA to describe the linear combinations of dependent variables that maximally discriminate among groups. In other words, MANOVA and DA corresponded to the inferential and descriptive aspects of analyses in much the same way as univariate ANOVA and subsequent multiple range tests do, because the last seek to describe where the differences among groups lie (McGarigal *et al.* 2000).

Significance of the MANOVA was assessed based on Wilks' lambda, the likelihood ratio statistic that tests the null hypothesis that the group means are equal in the population. In DA, each derived canonical variable is orthogonal (perpendicular) to the previous axis and describes progressively less information in the data set. The relative importance of each canonical variable in describing the multivariate data cluster was assessed by the relative magnitude of the eigenvalues expressed as a proportion of the sum of the eigenvalues.

The discriminant scores were derived from a linear combination of the original variables and represented the new multivariate data. I derived the centroid for each group and assessed distribution in multivariate space using multi-way 95% confidence intervals.

I used a multivariate analysis of covariance (MANCOVA) to model the influence of aircraft type (military jet, military cargo plane, floatplane or helicopter) and noise (L_{max}) on behaviour of paired harlequin ducks at Fig River. I modelled the influence of noise as a quadratic term because the behavioural response alert was non-linear (Goudie & Jones 2004). I was especially interested in the interaction term of aircraft and noise as a potential means to assess whether behavioural responses of harlequin ducks were independent of aircraft type.

RESULTS

Effects of aircraft disturbance on behaviour

I present data separately for females and males because I knew a priori that there were inherent gender differences in behaviours, particularly the display of greater vigilance by males (Squires 2003; Squires *et al.* 2006). There were substantial differences in behaviour between undisturbed and aircraft-disturbed female (Wilks' lambda $= 0.060, p < 0.0001$) and male (Wilks' lambda $= 0.094, p < 0.0001$) harlequin ducks at Fig River, Labrador (Table 2). In the presence of aircraft, alert behaviour, inactivity, comfort (preening) and vigilance increased significantly, and out of water behaviour decreased (Fig. 1). I modelled disturbed and undisturbed females and males together using a discriminant analysis in order to highlight differences indicated in the MANOVA (Wilks' lambda $= 0.0645, p < 0.0001$).

Harlequin ducks that were exposed to aircraft over-flights exhibited alert behaviour, became inactive and spent less time out of water (canonical variable 1 [CV1]; 73.1% of the variance). Paired males spent more time vigilant and less time preening than paired females (CV2; 24.3% of the variance) (Table 3). The CV1 provided maximum discrimination of the disturbed versus undisturbed cohorts, and I interpreted CV2 to be related to within-pair behaviour, particularly the role of increased vigilance by males within synchronized activities of pairs (Squires 2003; Goudie 2004). CV3 explained only 2.3% of the variance and I interpreted that it did not convey important information (Fig. 2).

Table 2 Univariate ANOVAs (females $F_{60,843}$; males $F_{55,850}$) from the MANOVA for paired adult harlequin ducks exhibiting undisturbed and aircraft-disturbed behaviour. ho = behaviour recorded out of water.

Behaviour	*Female*		*Male*	
	ANOVA	*p*	*ANOVA*	*p*
Agonistic	1.38	0.032	1.39	0.036
Agonistic (ho)	1.03	0.411	1.59	0.005
Court	0.47	0.999	0.47	0.999
Feed	2.13	< 0.0001	2.35	< 0.0001
Locomotion	2.59	< 0.0001	2.90	< 0.0001
Comfort	9.77	< 0.0001	5.71	< 0.0001
Comfort (ho)	2.37	< 0.0001	2.58	< 0.0001
Inactive	13.64	< 0.0001	13.52	< 0.0001
Inactive (ho)	2.37	< 0.0001	2.12	< 0.0001
Vigilant	9.90	< 0.0001	2.15	< 0.0001
Vigilant (ho)	2.15	< 0.0001	3.47	< 0.0001
Alert	5.54	< 0.0001	5.61	< 0.0001
Alert (ho)	0.98	0.5234	1.53	0.0094

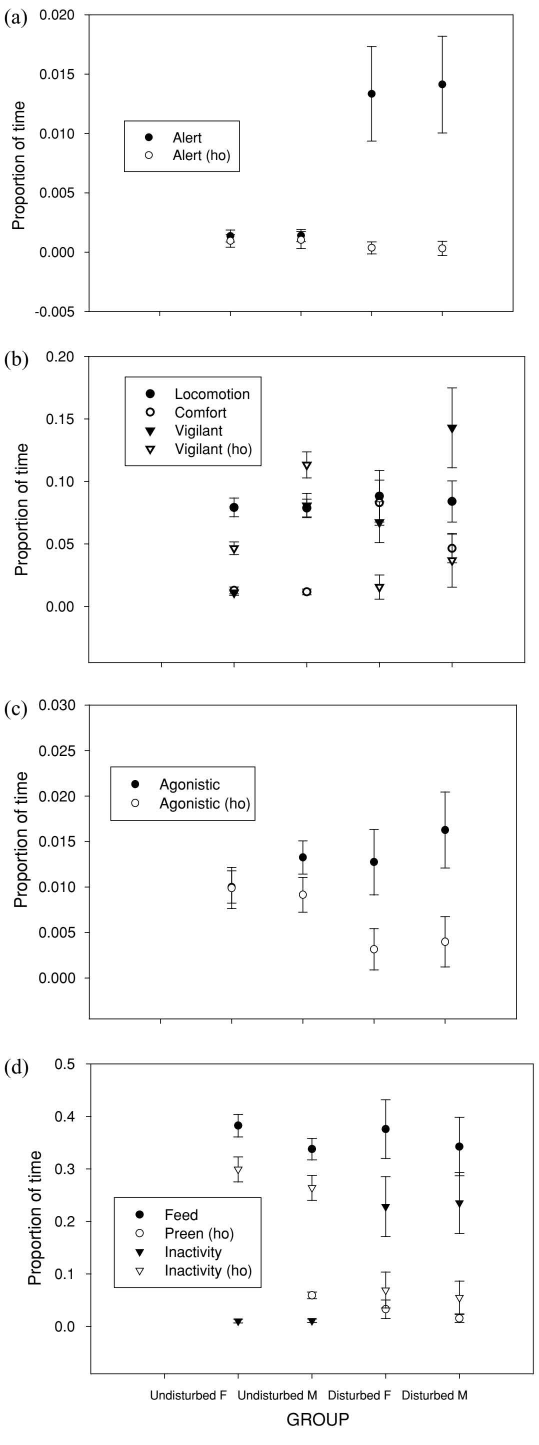

Figure 1 Mean (±95% confidence interval) proportion of time in behaviours for undisturbed and disturbed harlequin ducks at Fig River (Labrador). (*a*) alert and alert (ho), (*b*) locomotion, comfort, vigilant and vigilant (ho), (*c*) agonistic and agonistic (ho) (*d*) feed, preen (ho), inactivity and inactivity (ho). ho = behaviour recorded out of water, F = female, M = male.

Table 3 Correlations between discriminating variables and standardized canonical functions. Bold font indicates largest absolute correlation between each variable and discriminant function. ho = behaviour recorded out of water.

Behaviour	*CV1*	*CV2*	*CV3*
Inactive	**0.696**	−0.127	−0.196
Alert	**0.460**	−0.079	−0.171
Inactive (ho)	**−0.274**	−0.049	0.014
Vigilant (ho)	0.260	**0.618**	−0.276
Vigilant	−0.148	**0.579**	0.310
Comfort (ho)	−0.251	**−0.425**	−0.200
Feed	−0.011	**−0.145**	−0.001
Agonistic	0.053	**0.120**	−0.055
Comfort	0.451	−0.197	**0.745**
Locomotion	0.027	−0.013	**0.034**
% Variance	73.1	24.3	2.6

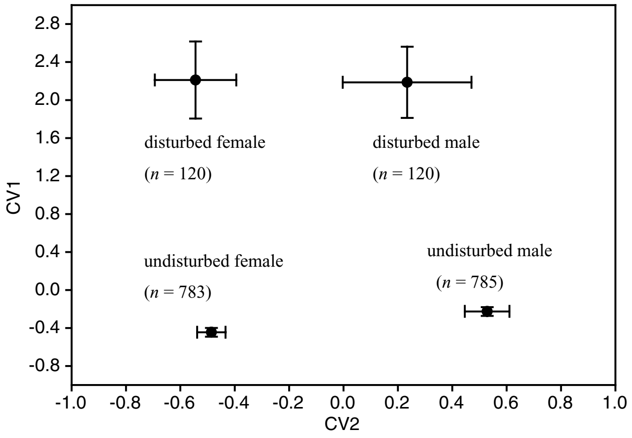

Figure 2 Behaviour of undisturbed and disturbed harlequin ducks at Fig River (Labrador) (centroids with 95% confidence intervals for discriminant scores). Discriminant scores are derived from linear combinations of original variables that maximize group separation. CV1 represented increasing alert and inactivity, and decreasing inactivity out of the water. CV2 represented increasing vigilance and decreasing preening.

Effects of aircraft type on behaviour

The behavioural effects of aircraft were most pronounced for military jets, although the precision of the magnitude of response for helicopter and fixed-wing over-flights was very low; this may be attributable to the small sample size (Fig. 3). There were significant differences in behaviour of harlequin ducks between types of aircraft (MANOVA: females Wilks' lambda = 0.0093, $p < 0.0001$, males Wilks' lambda = 0.0135, $p < 0.0001$). These differences were particularly marked for comfort, rest, vigilance and alert behaviours (Table 4).

Effects of aircraft type and noise on behaviour

Most aircraft noises of high amplitude were generated by military jets but the sample sizes for other types of aircraft were relatively small (Fig. 4). The MANCOVAs that incorporated aircraft type and noise (L_{max}) were significant (females Wilks' lambda = 0.1038, $p < 0.0001$; males Wilks' lambda = 0.1010, $p < 0.0001$). However, the interaction terms of aircraft type and noise were significant for important behavioural categories

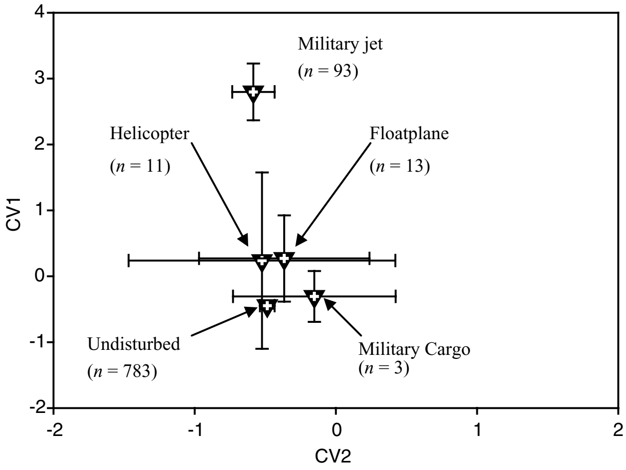

Figure 3 Behaviour of paired harlequin ducks at Fig River (Labrador) in relation to aircraft type (centroids with 95% confidence intervals for discriminant scores). CV1 represented increasing alert and inactivity, and decreasing inactivity out of the water. CV2 represented increasing vigilance and decreasing preening.

that differed between disturbed and undisturbed groups (Table 4). A curvilinear relationship of behaviours (CV1) with maximum noise level detected during standard 30-minute observation periods explained >40% of the overall variance in behaviour (females CV1 = 2.915 – 0.1225 L_{max} + 0.0011 L_{max2}, $F_{2,405} = 157.50$, $p < 0.00001$, $R^2 = 0.4375$; males CV1 = 1.618 – 0.084 L_{max} + 0.0009 L_{max2}, $F_{2,406} = 137.99$, $p < 0.00001$, $R^2 = 0.4047$; Fig. 5).

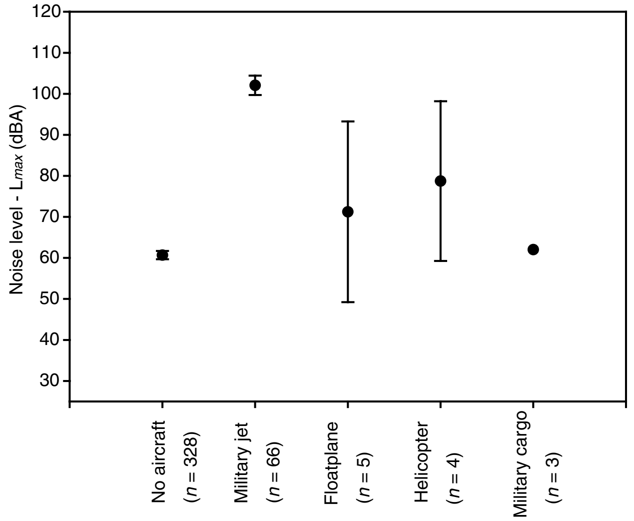

Figure 4 Mean noise levels (L_{max} in dBA with 95% CI) for four aircraft types measured during behavioural watches of paired harlequin ducks at Fig River (Labrador).

DISCUSSION

Effects of aircraft disturbance on behaviour

Harlequin ducks at Fig River, Labrador, responded to low flying aircraft by increasing alert behaviour and becoming inactive or immobile. The alert response to noise generated from low-level military jets increased in a dose-response manner (Goudie 2004; Goudie & Jones 2004). The multivariate approach used modelled the covariance among a suite of response behaviours that was not originally detected in the univariate analyses using a before-after-control-impact

Table 4 Univariate ANCOVAs of the MANCOVA for undisturbed and aircraft-disturbed behaviour for paired adult harlequin ducks versus aircraft type and noise. ho = behaviour recorded out of water, * = significant behavioural category in CV1 for discriminating disturbed from undisturbed groups.

Behaviour	*Noise (L_{max})*	*p*	*Aircraft type*	*p*	*Noise × type*	*p*
Paired females	$F_{1,286}$		$F_{32,286}$		$F_{32,286}$	
Feed	0.14	0.705	0.86	0.695	0.90	0.625
Preen	0.68	0.410	1.52	0.040	1.33	0.118
Preen (ho)	0.001	0.946	1.95	0.0023	1.88	0.004
Inactive*	0.04	0.840	6.72	< 0.0001	6.87	< 0.0001
Inactive (ho)*	0.09	0.765	0.50	0.990	0.51	0.987
Vigilant	1.47	0.227	0.86	0.691	0.87	0.675
Vigilant (ho)	0.00	0.981	0.53	0.985	0.54	0.982
Alert*	3.82	0.052	1.98	0.002	1.91	0.003
Alert (ho)	0.01	0.939	1.72	0.012	1.39	0.086
Paired males	$F_{1,295}$		$F_{30,295}$		$F_{30,295}$	
Feed	0.03	0.859	0.82	0.741	0.85	0.694
Preen	0.12	0.725	0.203	0.002	1.83	0.006
Preen (ho)	0.17	0.684	1.45	0.066	1.44	0.070
Inactive*	0.01	0.915	5.39	0.0001	5.49	0.0001
Inactive (ho)*	0.08	0.783	0.51	0.986	0.53	0.980
Vigilant	0.00	0.961	1.12	0.305	0.96	0.528
Vigilant (ho)	0.03	0.863	1.53	0.041	1.62	0.250
Alert*	6.87	0.009	3.08	< 0.0001	3.01	< 0.0001
Alert (ho)	0.06	0.804	3.11	< 0.0001	2.53	< 0.0001

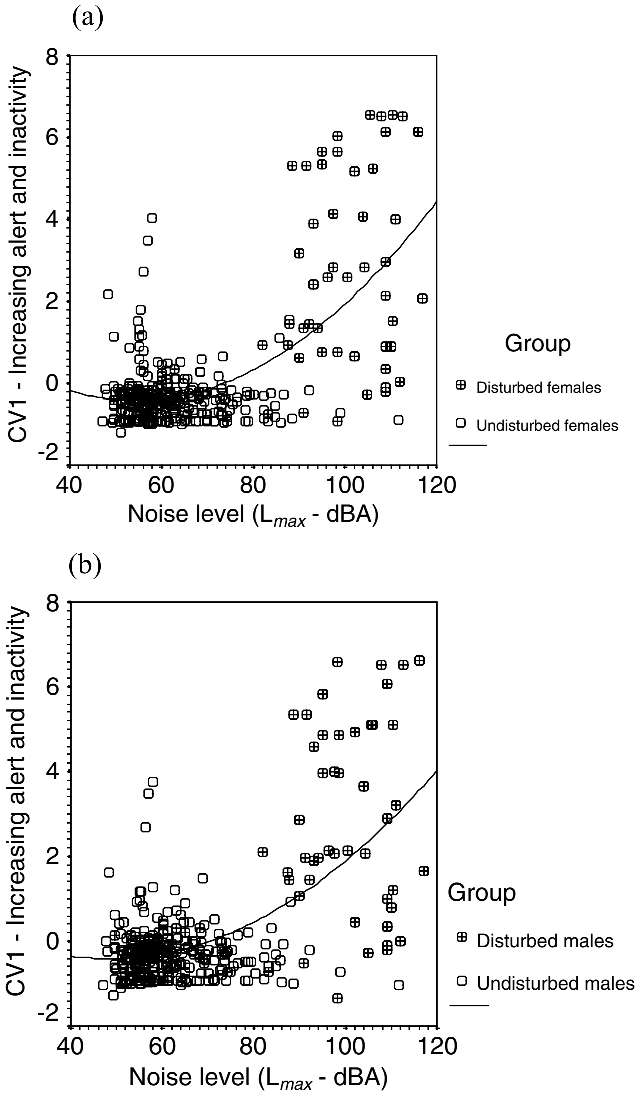

Figure 5 Relationship of canonical variable 1 to maximum noise level (L_{max} in dBA) detected during standard observation of harlequin ducks at Fig River (Labrador). (*a*) paired females and (*b*) paired males.

design. These findings are important because studies of effects of disturbance on behaviour may be biased to detecting overt responses (Trimper *et al.* 1998). Once animals stop moving or commence feeding or normal locomotion, observers may perceive that the individuals have returned to 'normal' behaviour (Harrington & Veitch 1991).

Detection of protracted or residual effects may be substantiated through before-during-after analyses (Goudie & Jones 2004), but are best evidenced through a multivariate statistical design because it models covariance that is otherwise masked in univariate analyses. Harrington and Veitch (1991) noted that 5–10 minutes elapsed before behaviour of caribou returned to pre-disturbance levels, and that it was likely that heart rate remained elevated for several minutes following a jet overpass. Inactivity can be part of the behavioural response to noise disturbance.

Effects of aircraft type and noise on behaviour

Noise generated from military jet over-flights can be very high in amplitude (for example up to 131 dB; Harrington & Veitch 1991; Goudie & Jones 2004). Sound pressure levels under 90 dB are less aversive to animals (Manci *et al.* 1988). In general, at Fig River there were stronger behavioural responses by harlequin ducks demonstrated for military jet over-flights than other aircraft (i.e. fixed-wing, helicopter or cargo plane), but my sample sizes for other aircraft were relatively small and I noted that, under certain conditions, responses to the other types of aircraft were relatively large; this accounted for the large demonstrated variance. At Fig River, the noise generated from military jet over-flights was of higher amplitude than other aircraft. The significant interaction term of aircraft type and noise (L_{max}) in the GLM of effects on behaviour indicated that it was not possible to separate effects of aircraft type from generated noise based on my relatively low samples of aircrafts other than military jets.

Noise may be the primary stressor in aircraft disturbance (Brown 1990, 2001*b*; Harrington & Veitch 1991; Ward *et al.* 2001) and 43.1% of the variance in the behaviour of paired harlequin ducks that were disturbed at Fig River was explained by noise. Causal association can most convincingly be established by demonstrating increase in response with increase in the level of exposure (Bowles *et al.* 1991; Bowles 1994). My findings could be applied to reduce effects of military jet noise on harlequin ducks in the Military Training Area of Labrador (Goudie 2004) by avoiding watersheds or reducing noise exposure by altitude limitations (Goudie & Jones 2004). Overall, these results support the need for studies directed towards population consequences of military aircraft disturbance.

At Fig River, most over-flights by military jets that coincided with behavioural observations of harlequin ducks were less than 100 m above ground level. It is possible that at such a low altitude the high amplitude noise masked any effect of aircraft type. Behavioural responses of animals may vary by aircraft type beyond some threshold of distance (Harrington & Veitch 1991). For example, Grubb and Bowerman (1997) argued that at distances to aircraft of less than 166 m there were no effects of aircraft type on behaviour of bald eagles (*Haliaetus leucocephalus*), whereas stronger responses to helicopters than to military jets and light planes were documented beyond this distance. Ward *et al.* (2001) demonstrated that noise generated from helicopters can increase with distance from the animals, and evidence supports that noise is the primary stressor in aircraft over-flights (Brown 2001*b*). Longer responses to helicopters than military jets may be a consequence of slower air speeds and greater visual detection. Additionally, helicopters actively pursue caribou (and closely approach eyries in raptor research; see Trimper *et al.* 1998) especially for wildlife research, and animals may associate this aircraft with the threat posed by predators.

CONCLUSIONS

Harlequin ducks responded to high amplitude noise generated by low-flying military jets. Responses were overt, including alert and startle behaviours, but also included less detectable effects, such as inactivity. The modelling of a suite of behaviours using multivariate techniques integrated the covariance structure and provided a holistic way to assess all behavioural aspects of the more immediate effects of aircraft over-flights. I conclude that conventional univariate approaches to studies of behavioural responses to disturbance may be biased by the a priori selection of response variables, because animals may not perform directly observable responses. A group of behaviours may be interrelated and engaged in the actual response, and this is best modelled through multivariate statistical analyses. The resulting canonical variables are linear combinations of the original variables and provide a more robust means to assess the relationship of behavioural response to noise dose.

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