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Responses of Pinnipeds to Navy Missile Launches at San Nicolas Island, California

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Abstract

To document the responses of pinnipeds to launches of missiles and similar aerial vehicles, three species of pinnipeds were observed during 77 launches from Navy-owned San Nicolas Island off California from August 2001 to October 2008. Pinniped behavior and flight sounds during each launch were recorded by unattended video cameras and acoustic recorders set up around the island's periphery, usually in pairs, as vehicles flew over or near haul-out sites. Multiple logistic regression was used to assess dependence of pinniped responses on received sound, distance from flight path, type of vehicle, and natural factors. The majority of observed California sea lions (*Zalophus californianus*) startled and showed increased vigilance up to 2 min after each launch; responses often included movement on the beach or into the water and were significantly related to received sound level and distance from the vehicle's closest point of approach. Most observed northern elephant seals (*Mirounga angustirostris*) showed little reaction to launches and merely raised their heads briefly. Nonetheless, their responses were also related to received sound level and distance from vehicle trajectory. The harbor seal (*Phoca vitulina*) was the most responsive species. During the majority of launches, most (average 68%; range 7 to 100%) observed harbor seals within ~4 km of the launch trajectory left their haul-out site by entering the water; harbor seals hauled out again at the same site several hours after a launch. Within the range of conditions studied, there was no clear correlation between harbor seal response and received sound level or distance from the closest point of approach of the vehicle. Despite these short-term behavioral reactions, the effects of launch operations are likely to have been minor and localized, with no consequences for local pinniped populations as pinniped population sizes on San Nicolas Island are stable or increasing.

Key Words: disturbance, launch sounds, missiles, California sea lion, *Zalophus californianus,* northern elephant seal, *Mirounga angustirostris*, harbor seal, *Phoca vitulina*

Introduction

The responses of pinnipeds to human activities vary widely (Richardson et al., 1995), with degree of disturbance dependent on species, disturbance type, intensity, and other factors. The literature on pinniped responses to missile launches and related activities is limited and includes a wide variety of vehicle types. Several species of pinnipeds have been documented to enter the water in response to vehicle launches, aircraft overflights, and sonic booms, but they generally hauled out again within several hours after the disturbance or by the next day (e.g., Bowles & Stewart, 1980; Stewart, 1982, 1993; Stewart et al., 1994a; Holst et al., 2005; ManTech SRS Technologies [MSRS], 2008). Although the primary effect of occasional missile launches on pinnipeds is likely to be short-term disturbance, there is also concern about stampedes and the crushing or abandonment of pups. Several studies have noted pup mortality related to abandonment by female pinnipeds during disturbance events, including overflights (e.g., Johnson, 1977; Wickens et al., 1992); however, direct mortality during disturbance-induced stampedes is rare (Richardson et al., 1995). Nonetheless, Lewis (1987) noted mortality of Steller sea lions (*Eumetopias jubatus*) due to human disturbance events. Also, walruses (*Odobenus rosmarus*) stampeding from haul-out sites during aircraft overflights have been reported to crush other individuals, especially calves (e.g., Loughrey, 1959; D. Fisher as cited in Johnson et al., 1989; Ovsyanikov et al., 1994). Still, no pup mortality has been observed during aerial vehicle launches at Navy-owned San Nicolas Island (SNI)

(Holst et al., 2005), large missile launches at Vandenberg Air Force Base (MSRS, 2008, 2009), or in response to simulated sonic boom sounds in California (Stewart, 1981, 1982). As existing knowledge is limited, there is a need to examine pinniped responses to launches of small- and moderate-sized vehicles as launch facilities are often situated along coastlines where pinnipeds haul out.

San Nicolas Island, one of the main islands in the Southern California Bight, supports large populations of breeding and molting California sea lions, northern elephant seals, and harbor seals at various times each year (Stewart & Yochem, 1984, 1994; Lowry et al., 1992; Hanan, 1996; Lowry, 2002). The U.S. Navy has been launching missiles, aerial targets, and other similar vehicles from SNI for over 50 y. The vehicles often fly over or near beaches around the periphery of SNI where pinnipeds are hauled out; some vehicles produce a sonic boom. Under the Marine Mammal Protection Act, the National Marine Fisheries Service (NMFS) issues authorizations to the Navy for disturbance of pinnipeds during launches from SNI. These authorizations allow the "take by harassment" of small numbers of California sea lions, northern elephant seals, and harbor seals during routine launches of small- and moderate-sized vehicles from SNI. The authorizations specify that acoustic and pinniped monitoring must take place in conjunction with the vehicle launches. The monitoring effort is intended to provide the information needed to document the nature, frequency, circumstances, and duration of changes in pinniped behavior resulting from the vehicle launches, including the occurrence of stampedes or injuries.

Herein we report on the 2001 to 2008 monitoring program at SNI. The specific objectives of the monitoring program were to (1) identify and document changes in behavior that occurred during and immediately after launches; (2) relate pinniped responses to distance from launch azimuth and received sound levels, with allowance for other factors that might influence responses; and (3) compare the responses of the three pinniped species.

Materials and Methods

Vehicle Launches

Two separate 1-y Incidental Harassment Authorizations (IHAs) were held by the Navy from 2001 to 2003; subsequent launch operations from October 2003 to October 2008 were conducted under Regulations (National Marine Fisheries Service [NMFS], 2003) and associated Letters of Authorization (LOAs). A total of 77 launches of 83 vehicles took place from SNI on 53 d from 2001 through 2008 (Table 1).

The launches involved either single vehicles, "dual" launches (two vehicles launched in quick succession within a span of ≤ 2 s), or up to three vehicles launched separately on the same day. In total, the Navy launched 29 Vandal target missiles, nine Coyote targets, 17 Advanced Gun System (AGS) slugs, 12 AGS missiles, 11 Rolling Airframe Missiles (RAM), and occasionally other missiles (two Arrows, one Falcon, one Tactical Tomahawk, and one Terrier Orion). Most of these vehicles are medium-sized missiles (1,000 to 4,000 kg at launch), but the AGS and RAM missiles are small (~70 kg). Vehicles were launched from one of two launch complexes on SNI. The Tomahawk and RAMs were launched from the Building 807 Launch Complex on the west coast of SNI (Figure 1), close to shore and 11 m above sea level. Until June 2004, AGS vehicles were launched from the Alpha Launch Complex, located 190 m above sea level on the west-central part of SNI (Figure 1); starting in July 2004, these vehicles were launched from the Building 807 Launch Complex. All other vehicles were launched from the Alpha Launch Complex. All launches occurred during daylight hours; and conditions ranged from clear and sunny to overcast and partly cloudy, with variable winds.

Acoustic Monitoring

Launch sounds were monitored near pinniped haul-out sites by Autonomous Terrestrial Acoustic Recorders (ATARs). On the day of each vehicle launch, up to three ATARs were positioned near pinniped haul-out sites at varying distances (up to 4 km) from the planned launch azimuth to record received in-air sound levels during launches. The ATARs were designed with separate channels to record both high-level sounds (e.g., from vehicle launches) and normal background (ambient) sounds. The ATARs recorded each sensor channel with a bandwidth of 3 to 20,000 Hz. The principal components of the ATARs included two calibrated dissimilar microphones (Piezotronics PCB 106B50 and TMS 130P10), two adjustable gain amplifiers/signal conditioners (PCB Piezotronics model 480E09), and a two-channel audio interface and analog-to-digital converter connected to a laptop computer. The microphones and signal conditioners were calibrated by the manufacturer and later recalibrated by either the manufacturer or Greeneridge Sciences. Microphones were placed in hemispherical windscreens, and each was affixed to an aluminum base plate (56 cm diameter, 6 mm thick) set on the ground.

Table 1. Vehicles launched from San Nicolas Island August 2001 through June 2007 (no launches in July 2007-October 2008); all three pinniped species were monitored during launches in Years 1-5, and harbor seals were not monitored during Year 6.

Launch dates	Number and types of vehicles launched	Launch azimuth (ºTrue)	Elevation angle	Launch complex	Altitude over beach (m)
Year 1					
August 2001-July 2002	14 Vandals	270-273.3°	8-42°	Alpha	390-2,926
	1 Terrier-Orion	232.3°	64.6°	Alpha	3,962
	2 AGS slugs	300-305°	62.5-63°	Alpha	152
	1 AGS missile	300°	62.5°	Alpha	1,615
	1 dual RAM	240°	8°	Building 807	15
Year 2					
August 2002-July 2003	5 Vandals	270-285°	8-42°	Alpha	396-5,266
	1 dual Vandal	273°	8°	Alpha	396
	2 Coyotes	270°	20-22°	Alpha	1,036-1,067
	1 Tactical Tomahawk	305°	90°	Building 807	30
	1 AGS slug	282°	50°	Alpha	1,372
	1 AGS missile	282°	50°	Alpha	1,372
	1 dual RAM	240°	10°	Building 807	15
Year 3					
May-September 2004	2 Coyotes	300°	18°	Alpha	1,006
	2 Arrows	285°	90°	Alpha	2,134
	4 AGS slugs	282-300°	50°	2 at Building 807 / 2 at Alpha	1,372
	1 AGS missile	282°	50°	Alpha	1,372
	3 RAMs	240°	10°	Building 807	15
	1 dual RAM	240°	8°	Building 807	15
Year 4					
January-October 2005	6 Vandals	270-273°	8-35°	Alpha	396-2,591
	1 dual Vandal	273°	8°	Alpha	396
	3 Coyotes	270°	14°	Alpha	914
	8 AGS slugs	280-287°	50-65°	Building 807	1,372-1,676
	7 AGS missiles	240-287°	50-65°	Building 807	1,372-1,676
Year 5					
February-May 2006	1 Falcon	280°	80°	Alpha	Hit land
	2 AGS slugs	235°	62.5°	Building 807	1,615
	2 AGS missiles	235°	62.5°	Building 807	1,615
Year 6					
April-June 2007	2 Coyotes	270°	14°	Alpha	914
	1 dual RAM	240°	10°	Building 807	15

Acoustic Analysis

From the recorded data for each launch, peak pressure, sound duration, root-mean-square sound pressure level (SPL) averaged over the duration, and M_{pa}-weighted sound exposure levels (SEL-M) were determined. The duration of transient launch sounds was defined as the period during which 90% of the launch sound energy was received. The recently defined M_{pa}-weighting procedure, appropriate for pinnipeds receiving strong airborne sound, is described in Southall et al. (2007). The M-weighting function is almost flat between the known or inferred limits of functional hearing for pinnipeds, but down-weights (attenuates) sounds at higher and lower frequencies. With M_{pa}-weighting, the lower and upper "inflection points" are at 75 Hz and 30 kHz. However, only the components up to 20 kHz were included here; components at 20 to 30 kHz were likely negligible in launch sounds.

Monitoring of Pinnipeds

Pinniped responses were documented by unattended video cameras set up several hours before each launch, generally at three of the haul-out

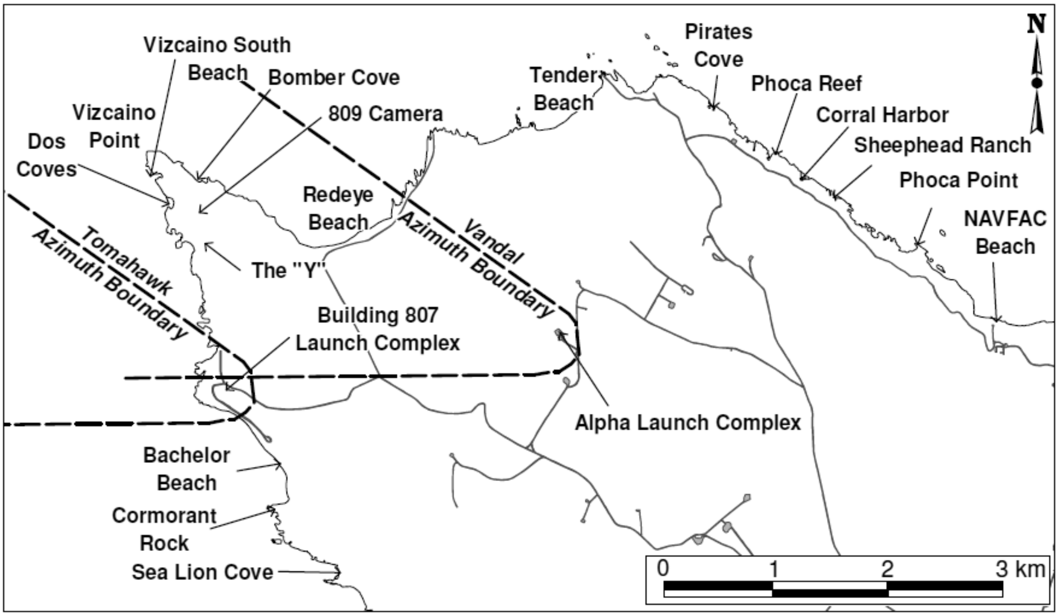

Figure 1. Map of San Nicolas Island, California, showing the vehicle launch sites (Alpha and Building 807 Launch Complexes) and the names of the beaches where pinnipeds and launch sounds were monitored; monitoring occurred at three of the named beaches during most launches, with specific monitoring sites varying among launches. The typical ranges of launch azimuths for vehicles leaving the two launch sites are indicated.

sites (usually the same three sites where ATARs were deployed). Remote cameras were essential because of safety rules associated with launches. Video recordings were made before, during, and after each launch. Care was taken not to disturb pinnipeds during camera set-up. Use of three video cameras allowed observations at three locations per launch, with up to three pinniped species monitored at each location, depending on the number of species hauled out at each site. Monitoring locations varied from launch to launch, depending on seasonal abundance of pinnipeds, logistics of equipment deployment, and a desire to acquire data (over the course of a sequence of launches) from a variety of haul-out locations and distances (0.5 to 4 km) from the launch azimuth. Navy environmental personnel also observed the pinniped groups directly prior to camera deployment and (sometimes, depending on logistics) during retrieval of the cameras to further document numbers of animals at the haulout. Details of field procedures are described in Holst et al. (2005).

Video Analysis

Digital video data were reviewed manually using a high-resolution monitor, and the following variables were transcribed: (1) group composition (i.e., species, number, sex and age class), (2) description and timing of the launch, and (3) number and proportion of pinnipeds that (a) moved and (b) entered the water during and immediately after the launch. These proportions of the monitored pinnipeds were determined by noting the total number of animals that reacted in these ways in relation to the total number of pinnipeds hauled out at the monitored site.

Data Analysis

To determine basic relationships between pinniped behavior and either proximity to the vehicle or received sound (SEL-M), Spearman Rank Order Correlations were calculated. Proximity of the launch was measured as the 3-dimensional (3-D) distance from the monitoring site to the closest point of approach (CPA) of the vehicle. The two response variables analyzed were "% that moved" and "% that entered water." One-sided *p*-values were derived because the direction of the effect was predictable. The analyses included data from all launches on all dates during all years of monitoring. To further investigate the effects of launches on pinniped behavior while allowing for various potentially confounding factors, we fitted logistic regression models to the two measures of behavioral response (Ramsey & Schafer, 2002) separately for the three pinniped species.

All logistic regression equations were of the form

$$\pi = \frac{\exp(\beta_0 + \beta_1\chi_1 + \beta_2\chi_2 + \ldots + \beta_k\chi_k)}{1 + \exp(\beta_0 + \beta_1\chi_1 + \beta_2\chi_2 + \ldots + \beta_k\chi_k)}$$

where π was the proportion of a given pinniped species (harbor seal, sea lion, elephant seal) that moved or entered the water after a launch; $\chi_1, \ldots, \chi_p$ were a set of predictor variables; and $\beta_0, \ldots, \beta_p$ were parameters to be estimated. The proportions, π, were calculated by dividing the number of individuals that moved or entered the water after a launch by the number of individuals that were on the beach at the time. Basic sample size was the number of launches, not the number of individuals.

Predictor variables considered for inclusion were predetermined based on their hypothesized effects on pinniped behavior after a launch. From this pool of predictor variables, backward model selection, with forward looks at the significance of previously removed variables, was used to determine the "best" set of predictor variables. From an initial model with all predictor variables, predictors were removed one at a time based on a significance value of 0.15. Between removals, previously eliminated variables were inspected and added back to the model if their significance value had become < 0.15.

The chi-square (χ^2) statistic for each coefficient and for the *p*-values associated with χ^2 statistics were also calculated. A multiplicative change in variance over and above that predicted by the binomial distribution (i.e., overdispersion) was estimated and used to adjust coefficient *p*-values (SAS Institute, 2000). Overdispersion parameters were estimated by including all predictor variables except measured sound levels in the model and computing the resulting Pearson χ^2 goodness-of-fit statistic. If χ^2 was > 1, the estimated overdispersion parameter was set equal to the square root of χ^2 for all models involving that species. If χ^2 was < 1, the overdispersion was set to 1.0. All subsequent model runs for a particular species, including model selection, included the species' estimated overdispersion parameter. Probability values for individual parameters were calculated by dropping the variable from the model, observing the change in total model fit (i.e., deviance), dividing the change in model fit by the overdispersion parameter, and comparing the result to a χ^2 distribution (McCullagh & Nelder, 1989). All calculations were carried out using *SAS Proc Logistic* and *SAS Proc GENMOD* (SAS Institute, 2000).

Two separate analyses were completed for each combination of response variable (moved and entered water) and pinniped species, one of which included the measured SEL-M and one that did not. In all, 12 models were fitted for the two response variables × three species × two variable sets (with and without SEL-M).

Predictor variables considered in the analysis were as follows: (1) vehicle type, (2) $\log_{10}$ of 3-D distance from recording site to CPA (LogCPADist; km), (3) angle above horizon from recording site to CPA of vehicle (CPA_Angle; in degrees), (4) wind component along CPA-to-pinnipeds axis (Wind; calculated as the cosine of the angle between wind direction and CPA-to-pinniped axis, multiplied by wind speed), (5) whether or not a previous launch had occurred the same day (Launch), (6) whether or not the launch occurred during pupping/breeding season (Season), (7) whether the launch produced a sonic boom (Sonic boom), and (8) SEL-M. Season was designated by codes "1" for pupping/breeding and "0" for non-pupping/ breeding. Wind strength and direction were measured at the SNI airport, located 152 m above sea level toward the east end of the island. Launch was coded as either "0" for a single or dual launch or the first launch in a multiple-launch series, or "1" for a launch preceded by another on the same day (i.e., the second or third launches in a widely spaced series). Vehicle type was incorporated as five variables representing whether (1) or not (0) the vehicle was an (1) AGS missile, (2) AGS slug, (3) RAM, (4) Coyote, or (5) "Other large" (e.g., Falcon, Arrow, Tomahawk, Terrier-Orion). Those five variables were all coded as "0" for Vandal launches (i.e., the Vandal was treated as the reference vehicle). For vehicles other than the Vandal, one of these five variables was coded as "1" and the others as "0."

Results

Video recordings of pinniped behavior during launches were obtained on 42 d at nine different sites for California sea lions (n = 127 site-date combinations), on 31 d at seven sites for northern elephant seals (n = 53), and 23 d at nine sites for harbor seals (n = 48). For each of these site-date combinations, the video recordings provided data on the responses of a sample of the total number of pinnipeds hauled out at that monitored site; samples consisted of up to 300 individuals (average 45 animals).

California Sea Lion

Although most California sea lions appeared startled and showed increased vigilance for a short period (< 2 min) after each launch, others hardly responded to the launches (Figure 2). On 100 of 127 occasions, some observed sea lions (1 to 100%; average 56%) reacted by moving around vigorously on the beach. On 39 occasions, up to

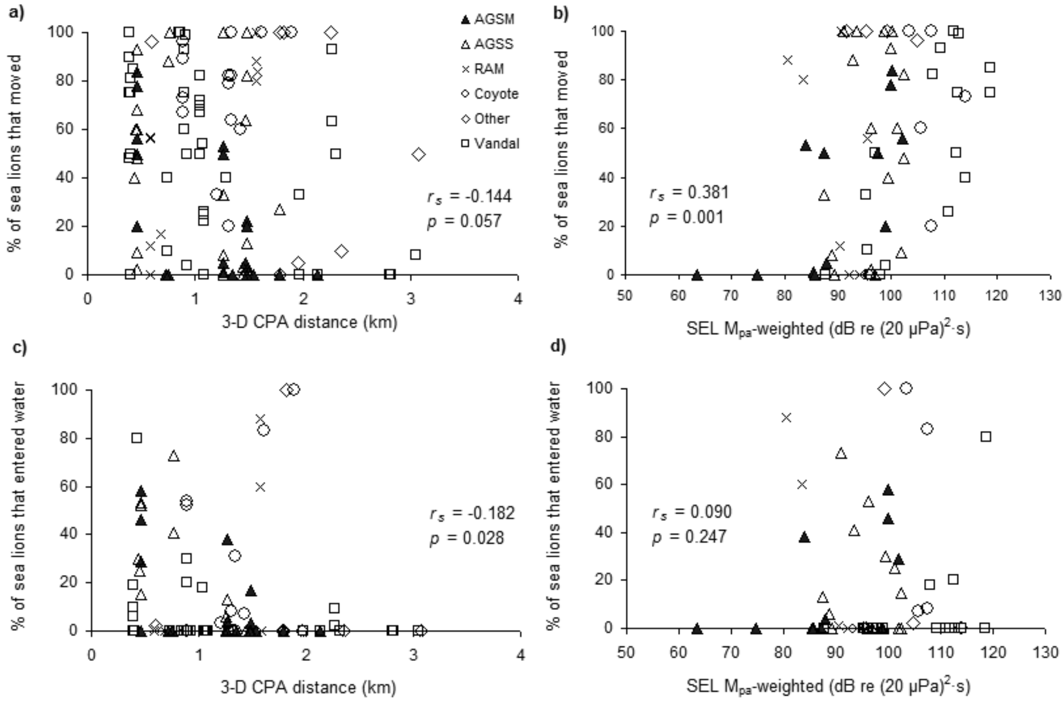

Figure 2. Percent of California sea lions that moved in relation to (a) 3-D CPA distance and (b) M_{pa}-weighted SEL for vehicles launched at SNI, and percent of California sea lions that entered the water in relation to (c) 3-D CPA distance and (d) M_{pa}-weighted SEL; also shown are Spearman rank correlation coefficients (r_s) and their 1-sided significance levels (p). See "Materials and Methods" for definitions.

100% (average 34%) of sea lions entered the water in response to a launch. Sea lions within 2 km of the CPA often entered the water in response to launches (Figure 2c). The majority of sea lions that remained on the beach resumed their pre-launch behaviors within 2 min after the launch.

Responses of sea lions to launches were related to SEL-M and CPA distance. Bivariate analysis showed that a greater percentage of sea lions entered the water with decreasing CPA distance from the vehicle (r_s = -0.182, p = 0.028, n = 112; Figure 2c). The relationship between decreasing CPA distance and percentage of sea lions that moved was only marginally significant (r_s = -0.144, p = 0.057, n = 121; Figure 2a).

The logistic regressions that did not consider received sound level showed that the proportions moving and entering the water were highly significantly and inversely related to LogCPADist when other variables were taken into account ($p \leq 0.001$; Table 2). The proportion that moved also depended on the type of vehicle launched. Compared to proportions that moved during launches of the relatively large Vandal targets, the proportion moving was significantly higher during Coyote target launches and lower during launches of small AGS missiles.

When the measured launch sound (SEL-M) was included in the regression, the proportion of sea lions that moved was strongly and positively related to sound level ($p \leq 0.001$; Figure 2b & Table 3). After consideration of measured sound level, CPA distance no longer had much additional effect on the proportion moving. However, even after allowance for sound level, there were significant differences in the proportions of sea lions that moved in response to different vehicle types (Table 3). For a given received sound level, responses were similar for the Coyote and Vandal targets ($p > 0.1$), but responses to other vehicles (both small and large) tended to be greater ($p \leq 0.01$ in each case; Table 3). In addition, a greater proportion of sea lions moved in response to launches during the nonbreeding season (Tables 2 & 3).

Northern Elephant Seal

The majority of northern elephant seals exhibited little reaction to launch sounds. On most occasions, observed elephant seals merely raised their heads briefly during the launch and then quickly

Table 2. Coefficients and nominal significance levels for best-fit regression models relating pinniped response (proportion that moved, proportion that entered the water) to non-sound predictor variables; *n* = number of monitoring occasions (i.e., site-launch combinations), and Intercept = y-intercept of the regression equation. For definitions of predictor variables and basis for excluding some variables (marked "--") from the final models, see the "Data Analysis" section under "Materials and Methods." Elephant seals entered the water too rarely to justify analysis.

	Sea lion		Elephant seal	Harbor seal	
	Moved (n = 118)	Water (n = 118)	Moved (n = 46)	Moved (n = 45)	Water (n = 45)
AGS missile	-1.264 **	--	-3.414 ***	--	--
AGS slug	-0.661 (*)	--	-2.214 ***	--	--
RAM	-0.281 ns	--	-2.123 *	--	--
Coyote	1.225 **	--	-1.458 *	--	--
Other large	0.953 ns	--	-2.063 *	--	--
Sonic boom	--	0.650 ns	--	--	--
LogCPADist	-2.765 ***	-2.988 ***	-2.282 *	--	--
CPA_Angle	--	--	0.046 **	0.074 ***	0.038 **
Season	-0.791 **	-0.575 ns	--	1.978 **	1.707 ***
Wind	--	--	0.223 **	0.110 (*)	--
Launch	--	--	--	--	-0.934 *
Intercept	0.390	-2.114	-2.512	-0.891	-0.740

Note: *** means nominal $p \leq 0.001$; ** $0.001 < p \leq 0.01$; * $0.01 < p \leq 0.05$; (*) $0.05 < p \leq 0.1$; and ns (not significant) means $p > 0.1$

returned to their previous activity (e.g., sleeping). However, on 24 of 53 occasions, a small proportion (average 24%) of elephant seals on the beach repositioned or moved a small distance (< 2 m) away from their resting site but settled within 30 s. The proportion of elephant seals that entered the water was typically zero, although some elephant seals were seen to enter the water on three occasions during launches of one Coyote (37% of the elephant seals), one Vandal (2.5%), and one RAM (1%).

Responses of elephant seals to launches, although limited, were related to SEL-M and CPA distance. The percentage of elephant seals that moved increased with decreasing CPA distance (r_s = -0.311, p = 0.015, n = 50; Figure 3a) and increasing SEL (r_s = 0.627, p < 0.001, n = 27; Figure 3b). Similarly, the logistic regression without SEL-M showed that response of elephant seals was significantly related to LogCPADist and to vehicle type ($p \leq 0.05$; Table 2). Elephant seals tended to be more responsive when larger vehicles, such as Vandals and to a lesser degree Coyotes, were launched (Table 2). When sound was considered, SEL-M was a better predictor ($p \leq 0.001$) of elephant seal response than CPA both in a simple bivariate sense (Figure 3b vs Figure 3a) and in a multivariate sense (Table 3). Once SEL-M was considered, there was no residual effect of vehicle type on proportion moving (Table 3). Although elephant seals entered the water on only three occasions (SEL measurements were available for two of those occasions), the tendency to enter the water was marginally higher with increasing SEL-M (r_s = 0.292, p = 0.068, n = 27; Figure 3d).

Table 3. Coefficients and nominal significance levels for best-fit regression models relating pinniped response (proportion that moved, proportion that entered the water) to sound and non-sound variables; otherwise as in Table 2.

	Sea lion		Elephant seal	Harbor seal	
	Moved (n = 62)	Water (n = 55)	Moved (n = 26)	Moved (n = 31)	Water (n = 31)
SEL-M	0.235 ***	--	0.268 ***	--	0.043 ns
AGS missile	3.232 **	--	--	--	--
AGS slug	3.304 **	--	--	--	--
RAM	4.229 **	--	--	--	--
Coyote	-1.134 ns	--	--	--	--
Other large	3.346 **		--	--	--
Sonic boom	--	--	--	--	--
LogCPADist	2.675 (*)	-3.119 **	--	--	6.992 *
CPA_Angle	--	--	-0.063 **	0.095 ***	0.041 *
Season	-1.344 **	-0.759 ns	--	--	--
Wind	--	--	--	0.260 **	--
Launch	--	--	--	--	--
Intercept	-24.983	-1.637	-28.288	-1.534	-6.556

Note: *** means nominal $p \leq 0.001$; ** $0.001 < p \leq 0.01$; * $0.01 < p \leq 0.05$; (*) $0.05 < p \leq 0.1$; and ns (not significant) means $p > 0.1$

Harbor Seal

During the majority of launches, most harbor seals left their haul-out sites and entered the water, including those hauled out at sites as far as 3.5 km from the CPA. On 34 of 48 occasions, up to 100% (average 68%) of observed harbor seals entered the water. Harbor seals that left their haul-out site generally did not return during the duration of the video-recording period, which typically continued for 1 to 2 h after the launch. Numbers of seals hauled out at the same site several hours after a launch or the next day were generally similar to pre-launch counts.

Harbor seal responses (proportions moving and entering water) were not strongly related to either CPA distance or measured SEL-M within the range of distances and received sound levels encountered at the study sites (Figure 4; Tables 2 & 3). The proportion that moved was weakly related to decreasing CPA distance in a bivariate sense (r_s = -0.231, p = 0.062; n = 45; Figure 4a), but this trend was not significant after other variables were considered (Table 2). LogCPADist was a significant predictor ($p \leq 0.05$) of the proportion that entered the water only for the logistic regression that included sound (Table 3). Some harbor seals entered the water when received sound levels were as low as 64 dB re (20 µPa)$^2 \cdot$ s SEL-M, but others remained on their haul-out sites with SEL-M as high as 112 dB re (20 µPa)$^2 \cdot$ s (Figure 4d).

Harbor seal response did increase significantly with increasing CPA angle (i.e., with increasing elevation angle from the haul-out site to the vehicle when the vehicle was at CPA) (Tables 2 & 3). There was also a tendency for more harbor seals to move into the water when the wind was directed from the vehicle's CPA location toward the haul-out site ($p < 0.01$; Table 3). When sound level was not considered, harbor seals were significantly more responsive ($p < 0.01$) to launches during the pupping/breeding season (Table 2), but that trend was not evident after allowance for sound (Table 3). Unlike the situation for the other two species, there was no tendency for consistent differences in responsiveness to the various vehicle types.

No evidence of injury or mortality was evident during or immediately succeeding the launches. However, on three occasions, harbor seal pups were observed to be knocked over by adult harbor seals as the adults and pups moved toward the water in response to the launch. Seal pups were momentarily startled but did not appear to be injured, and they continued to move toward the water.

Discussion

Previously, we reported on the responses of pinnipeds to 31 launches of small- and moderate-sized vehicles from SNI during 2001 to 2003 (Holst et al., 2005). From 2003 to 2008, numerous additional vehicles, and more types of vehicles, were launched from SNI. This has allowed a more detailed analysis of pinniped responses, including use of a multivariate approach to evaluate whether various other factors affected the magnitude of pinniped responses to launches during 2001 to 2008.

In general, pinniped behavioral responses to launches were, with the exception of some harbor seals, usually brief. Northern elephant seals exhibited little reaction to the launches, even when exposed to sound levels as high as 119 dB re (20 µPa)^2 · s SEL-M (Figure 3). California sea lions showed stronger but variable responses. Harbor seals were the most responsive and frequently moved into the water during launches, even when the CPA of the aerial vehicle was as far as 3.5 km away and SEL-M was as low as 64 dB re (20 µPa)^2 · s.

These results are consistent with those obtained from smaller samples from the first 2 y of monitoring (Holst et al., 2005). Similarly, several other studies have noted that elephant seals generally showed no more than a momentary alert reaction when exposed to sounds that caused nearby harbor seals and California sea lions to flee (e.g., Stewart, 1982; MSRS, 2008). Harbor seals have also been shown to respond to some sonic booms, overflights by light aircraft, and space vehicle launches by flushing into the water (Bowles & Stewart, 1980; Stewart et al., 1994a; MSRS, 2008). Although MSRS (2008) noted that California sea lions and harbor seals were more responsive during launches of large missiles that produced a

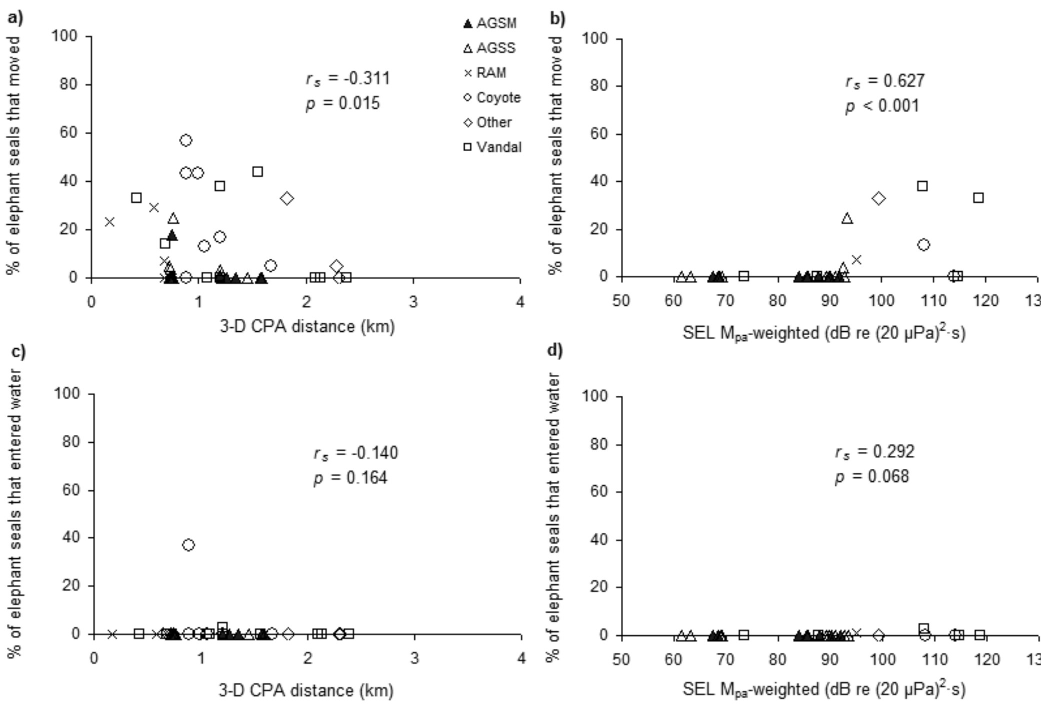

Figure 3. Percent of northern elephant seals that moved in relation to (a) 3-D CPA distance and (b) M_{pa}-weighted SEL for vehicles launched at SNI, and percent of elephant seals that entered the water in relation to (c) 3-D CPA distance and (d) M_{pa}-weighted SEL; also shown are Spearman rank correlation coefficients (r_s) and their 1-sided significance levels (p).

sonic boom than during launches when no sonic boom was received, this was not evident in our study involving smaller missiles.

All measured SEL-M values near pinniped beaches during vehicle launches were below the 129 dB re (20 µPa)^2·s level that may induce mild temporary threshold shift (TTS) in harbor seals (Southall et al., 2007), and few (if any) of the monitored pinnipeds were exposed to sound levels above 122 dB SEL-M. However, several launches produced sonic booms whose impulses (as measured at haul-out sites) exceeded 143 dB re 20 µPa, the peak pressure level estimated to elicit onset of TTS in harbor seals. Pinnipeds (mostly California sea lions) monitored at beaches where sounds exceeded 143 dB re 20 µPa did not always enter the water. During three Vandal launches, measured peak pressure levels near a sea lion and harbor seal haul-out site reached ~150 dB re 20 µPa, that is, slightly exceeding the 149 dB re 20 µPa level above which permanent threshold shift (PTS) might occur in harbor seals (Southall et al., 2007). TTS and PTS thresholds appear to be higher for California sea lions and northern elephant seals than for harbor seals (Kastak et al., 2005; Southall et al., 2007). Thus, it is possible that a few pinnipeds, particularly harbor seals, may have incurred mild TTS during launches of larger (Vandal and Coyote) vehicles. However, there was little potential for PTS as harbor seals were not hauled out on beaches where sound levels were ≥ 149 dB re 20 µPa. Vandal targets are no longer launched from SNI, but other medium-sized vehicles producing similar sound levels are launched occasionally.

In evaluating factors influencing pinniped responses to launches, it was not possible to consider all potential predictor variables. Most of the logistic regression models, especially those that considered SEL-M in the pool of potential predictor variables, suffered from low sample sizes. In addition, several models, particularly those involving elephant seals, suffered from partial incomplete separation and would not converge. Partial incomplete separation occurred when none of the animals responded during two or more vehicle flights that occurred with similar values of the predictor variables. For example, if no elephant seals ever responded to any launches of an AGS missile or slug, the model would suffer from partial incomplete separation. Partial incomplete separation was largely caused by low sample size.

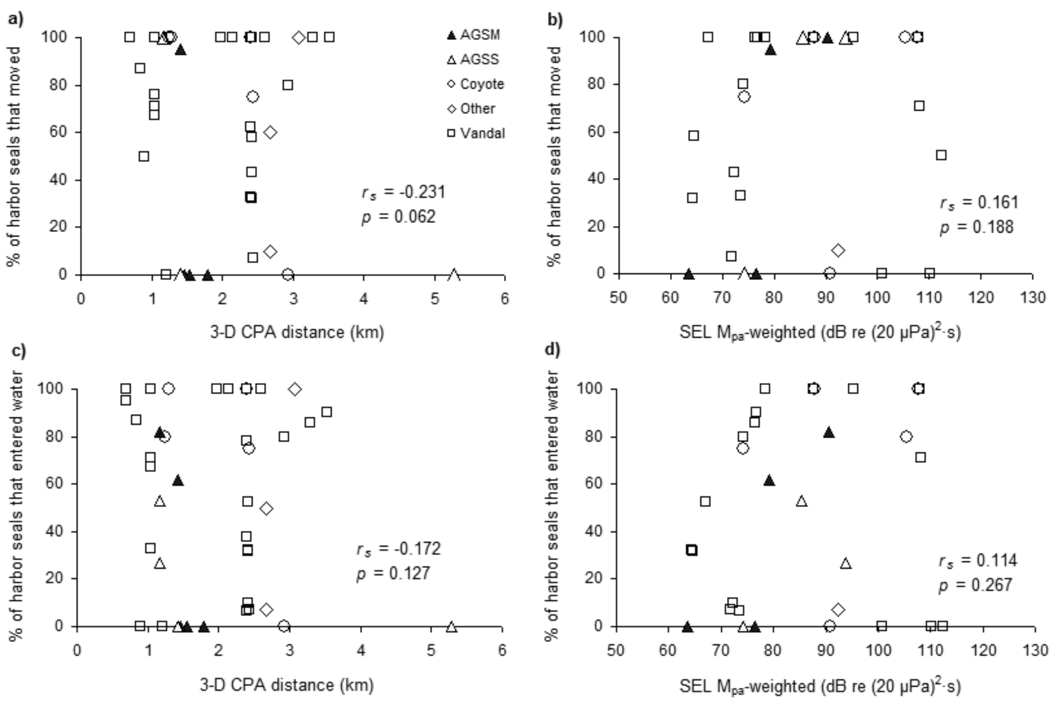

Figure 4. Percent of harbor seals that moved in relation to (a) 3-D CPA distance and (b) M_{pa}-weighted SEL for vehicles launched at SNI, and percent of harbor seals that entered the water in relation to (c) 3-D CPA distance and (d) M_{pa}-weighted SEL; also shown are Spearman rank correlation coefficients (r_s) and their 1-sided significance levels (p). Harbor seals were not monitored during RAM launches.

In cases when incomplete separation prevented estimation, the model was reduced (i.e., variables were eliminated) until separation of responses was achieved and the models converged.

The analyses showed that responses of pinnipeds were affected by several factors, including proximity of the animals to the vehicle flight path, sound exposure level, or both, along with (for some situations) vehicle type, elevation angle from haul-out site to the vehicle's CPA position, season, and wind conditions. Besides the variables examined here, other factors such as weather, tide state, and time of day are also expected to play a part in determining pinniped behavior and responsiveness (e.g., Bowles & Stewart, 1980). Although pinnipeds are known to habituate to some human disturbance such as frequent overflights (e.g., M. Bigg as cited in Johnson et al., 1989), harbor seals and California sea lions continue to respond to the launches at SNI despite occasional exposures over many years. However, the number of pinnipeds that were disturbed during the launches was small, and any effects appeared to be minor, short-term, and localized, with no consequences for local pinniped populations. Pinniped populations on SNI have been relatively stable (harbor seals) or growing (elephant seals, California sea lions) despite ongoing vehicle launches since the 1950s (Lowry et al., 1992; Stewart et al., 1994b; Hanan, 1996; Lowry, 2002). Similarly, Stewart (1981) reported that habitat use, population growth, and pup survival of northern elephant seals and California sea lions did not appear to be affected by periodic exposure to impulse noise. Elsewhere, Perry et al. (2002) noted no significant differences in beach counts of gray seals (*Halichoerus grypus*) or harbor seals following sonic booms and, at least for gray seals, a long-term upward trend in numbers over the years with recurring sonic booms. Nonetheless, at SNI, behavioral observations of California sea lions and harbor seals will continue during launches in order to meet regulatory requirements and to obtain a better understanding of factors that affect short-term responses of pinnipeds.

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