Aquatic Mammals 2009, *35*(4), 445-451, DOI 10.1578/AM.35.4.2009.445

Correlating Whale Strandings with Navy Exercises off Southern California

Ronald Filadelfo,[1] Yevgeniya K. Pinelis,[1] Scott Davis,[1] Robert Chase,[1] Jonathon Mintz,[1] Jessica Wolfanger,[1] Peter L. Tyack,[2] Darlene R. Ketten,[3] and Angela D'Amico[4]

[1]*Center for Naval Analyses, 4825 Mark Center Drive, Alexandria, VA 22151, USA; E-mail: filadelr@cna.org*
[2]*Woods Hole Oceanographic Institution, Biology Department, 266 Woods Hole Road, Woods Hole, MA 02543-1049, USA*
[3]*Woods Hole Oceanographic Institution, Biology Department, 266 Woods Hole Road, Woods Hole, MA 02543-1049, USA, and Harvard Medical School, Department of Otology and Laryngology, 243 Charles Street, Boston, MA 02114, USA*
[4]*Space and Naval Warfare Systems Center Pacific, 53560 Hull Street, San Diego, CA 92152-5001, USA*

Abstract

There have been several incidents when Navy sonar operations at sea coincided in time and location with the mass stranding of marine mammals, particularly beaked whales. Filadelfo et al. (this issue) compiled historical data on large-scale naval exercises and found significant correlations with whale mass strandings in some locations but not in others. In the present study, we compile information on Navy operations off southern California and single strandings of several cetacean species to see if there is a correlation between strandings and Navy exercises in this area. We use information on the state of decomposition of the stranded animals to treat the actual time of stranding as a random variable, and we simulate the correlation between Navy activity and strandings with a Monte Carlo model. For gray whales (*Eschrichtius robustus*), the 95% confidence interval (CI) for the ratio of odds of a stranding occurring as a result of Navy exercises to the odds of a stranding occurring naturally was (0.879, 1.582), consistent with the null hypothesis of no difference in stranding rates between times of Navy exercises and other times. For other species, the 95% CI for the odds ratio was (0.716, 1.394), which is, again, consistent with the null hypothesis.

Key Words: whale strandings, military sonar

Introduction

Scientific and legal debate continues regarding the effect of military mid-frequency active sonars (MFAS) on marine mammals. Cox et al. (2006), Filadelfo et al. (this issue), and D'Amico et al. (this issue) compiled historical data on large-scale naval exercises and whale mass strandings. The fundamental questions remaining are as follows: How and under what conditions does use of MFAS affect marine mammals, and under what conditions might MFAS impel whales to strand?

To continue exploring possible links between sonar use and whale strandings, we examined individual stranding occurrences and Navy exercises in southern California. As in Filadelfo et al. (this issue), data on sonar use and whale strandings were examined for correlations in time and location. The other studies examined potential correlations between beaked whale mass strandings and naval exercises. This study focuses on single stranding data from all cetacean species, adding additional data such as decomposition states that are available for southern California, and employs a methodology that has not been used previously. Based on the state of decomposition of each stranded animal, we estimated the time delay between the actual time of the stranding and the time first reported as a random variable. We then simulated the correlation between Navy exercises and strandings with a Monte Carlo model.

Materials and Methods

Data

Timelines of southern California Navy exercises were reconstructed using the procedures described in Filadelfo et al. (this issue). We focused on exercises that included anti-submarine warfare (ASW) training and during which, at some time, MFAS was likely to have been used.

In Filadelfo et al. (this issue), Evans & England (2001), Freitas (2004), and D'Amico et al. (this issue), only mass strandings were examined for coincidence with naval operations. Individual strandings are far more common than mass strandings and thus produce "noisier" data, making the analyses more complex than those for mass strandings. In addition, although mass strandings occur naturally for a variety of reasons (many of which remain unknown), mass strandings are rarer for most species and are more often found to be correlated with an extrinsic, broad event such as a pollutant than with isolated animal strandings. For this analysis, we use data on single strandings that occurred in southern California, despite the difficulty in determining the factors contributing to an individual stranding. Our data set does include one mass stranding event: three pygmy sperm whales on 9 April 2006. All other stranding events in our data are singles.

We obtained data on California strandings covering the 8,923-d period from 29 November 1982 to 23 March 2007 from NOAA's Southwest Stranding Center located in Long Beach, California. The original stranding report forms (generally field reports and Level A data sheets) were digitized and used to determine geographic locations from specific data or descriptions as well as information on animal states. Figure 1 shows all reported whale strandings off California between 29 November 1982 and 23 March 2007. Each X marks the location of a whale stranding reported in the data. There are some obviously erroneous position reports—for example, strandings inland as well as several positions reported at sea but noted as on shore. Some at-sea positions, however, did represent observations of floating whale carcasses. For our analyses, we restricted data to reports of strandings that were within a geographic range consistent with a possibility of being affected by MFAS use off southern California, specifically in the waters near San Clemente Island where the Navy performs most of its training. Therefore, our correlation analyses include only strandings that occurred from latitude 34° N, approximately the northern boundary of the Navy's Southern California Operating Area (U.S. Department of the Navy [U.S. DoN], 2005; Global Security, 2009), south to the U.S.-Mexico border. The data set contained a few entries of "unknown species." These were generally reports of unidentifiable bones or organic matter on a shoreline with no knowledge of how long they were there or what exactly they were. We excluded these reports from our analyses.

D'Amico et al. (this issue) compiled a global beaked whale mass stranding database from many sources, including journal and newspaper articles through the end of 2004. The data utilized in this study are compiled from available stranding reports that generally include more detailed information on the state of decomposition of the animal at the time of observation than in the broader literature. Such information, depending upon its level of detail, can be used to estimate the time lag between probable beaching and the

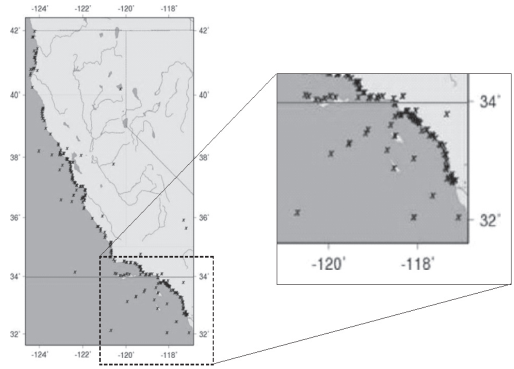

Figure 1. California strandings, 1982 to 2007

first reports of the stranded animal. The condition of the animal conventionally is reported as one of five categories or codes: (1) first seen alive; (2) freshly dead, or seen live then died; (3) relatively good condition with most organs intact, but they may be distended and clear evidence of autolysis underway; (4) moderate to severe decomposition; and (5) advanced decomposition, sometimes lacking most organs, or skeletal remains only. When a stranding report is filed, the individual filling out the report selects the category that in his or her judgment best describes the condition of the carcass. Through discussions with the NOAA Southwest Stranding Center, we determined average potential postmortem times (given as a range of days from probable stranding date to observation) based on the codes and implied levels of decomposition noted at the time of examination.

Analysis Procedure

Our analysis of strandings vs Navy exercises consisted of timeline analyses similar to those described in Filadelfo et al. (this issue). The timeline of Navy exercises in southern California is the same one used in that reference, with our statistical analyses restricted to the period 29 November 1982 to 23 March 2007. By contrast, for this more restricted California regional study, we determined the correlation between exercises and strandings by treating the age of the stranding (the time lag between the actual time of the stranding and the time it was observed) as a random variable and calculating the correlation between exercises and strandings with a Monte Carlo approach.

Given the available information on the state of the whale carcass, it would be useful to have a method allowing accurate adjustment of the date of the whale stranding, particularly since most strandings occur earlier than the reported stranding date. One method would be to simply choose a particular adjustment factor for all strandings within a decomposition category and apply that adjustment factor to all reported strandings in that category. For example, if carcasses classified as displaying moderate decomposition are assumed to have died 4 d to 2 wks before the date they are observed and reported, we could simply assume that all strandings in this classification actually occurred 9 d (mean value of the range) earlier than we observe in the data. However, this approach is problematic because our results are dependent on this particular choice of adjustment factor.

Although the classification of the state of decomposition is subjective in our data set, it does provide us with additional information that can be useful for our analysis. NOAA Stranding Center personnel provided the following guidance concerning the likely age of stranding observations (J. Cordero, NOAA Southwest Stranding Center, pers. comm.):

- Codes 1 & 2, observed alive or clearly very recent death: no adjustment
- Code 3, good postmortem condition: adjust by 2 to 3 d
- Code 4, moderate to severe decomposition: adjust by 4 d to 2 wks
- Code 5, advanced decomposition: adjust by 2 to 6 wks

Because stranding database guidance does not provide sufficient information to inform our choice of a single adjustment, any choice we might make would be arbitrary. As a result, we instead use statistical methods that account for our uncertainty with respect to the correct adjustment factor. We make two assumptions regarding the relationship between the reported stranding dates and the actual stranding dates. First, we assume that the actual stranding date is equal to the reported date minus an adjustment factor that falls in the range specified for the corresponding decomposition category. Second, we assume that within the specified adjustment range for a given decomposition category, each adjustment factor in that category is equally likely. Under these two assumptions, we can simulate adjustment factors for all strandings in the data set. This simulation process explicitly incorporates our uncertainty about the true date for each observed stranding and implicitly assumes animals do not swim for several days to a stranding location following exposure to sonar.

The simulation procedure used is as follows. For the 8,923-d period covered by our data set, 180 strandings were reported. We first simulate adjustment factors for each of the 180 strandings by generating random numbers for each stranding from the appropriate interval given the decomposition classification of the carcass. For example, if a stranding is categorized as being in an advanced state of decomposition, we draw a random number from the interval (14, 42) since we are assuming that the true date of the stranding is from 2 to 6 wks earlier than reported.

In general, a given data set of strandings can be presented as a contingency table as shown in Table 1.

Table 1. Description of cell entries for 2 × 2 contingency table

	No Navy exercise	Navy exercise	Total
No strandings	A - X = C - (B - X)	D - X	A
Strandings	B - X	X	B
Total	C	D	T = A + B = C + D

In this table, T = the total observation period in days, A = the number of days with no strandings, B = the number of days with strandings, C = the number of days with no Navy exercises, and D = the number of days with Navy exercises. A, B, C, D, and T remain fixed for our calculations. The number (X) of strandings that coincided with Navy exercises can change with each simulation run, and together with the fixed row and column totals, it determines the other three cells of the table.

We examined the strength of the relationship between Navy exercises and whale strandings by estimating an odds ratio. The odds (O_E) of a whale stranding on days of Navy exercises can be calculated as

$$O_E = \frac{\Pr(\text{Stranding} \mid \text{Navy Present})}{\Pr(\text{NoStranding} \mid \text{Navy Present})} = \frac{X/D}{(D-X)/D} = \frac{X}{D-X}.$$

Similarly, we can compute the odds (O_N) of a whale stranding on days without Navy exercises as

$$O_N = \frac{\Pr(\text{Stranding} \mid \text{No Navy Present})}{\Pr(\text{No Stranding} \mid \text{No Navy Present})} = \frac{(B-X)/C}{(A-X)/C} = \frac{B-X}{A-X}.$$

We are interested in the ratio (O_R) of these:

$$O_R = \frac{O_E}{O_N} = \frac{X(A-X)}{(D-X)(B-X)}.$$

In particular, we want to know if this odds ratio is close to 1. If it is, then there is no evidence for a relationship between the odds of stranding and Navy exercises. If the odds ratio is significantly bigger than 1, then the odds of a stranding are higher when the Navy exercises are conducted.

Let u_r represent one set of adjustment factors for all 180 reported strandings and let x_r represent the number of strandings that coincided with Navy exercises. Then, given the constraints of 180 reported strandings, 8,923 total observation days, and 1,588 days of Navy exercises, we obtain the contingency table shown in Table 2.

Table 2. Contingency table for 8,923-d observation period, 1,588 d of Navy exercises, and 180 strandings

	No Navy exercise	Navy exercise	Total
No strandings	7,335 - (180 - x_r)	1,588 - x_r	8,743
Strandings	180 - x_r	x_r	180
Total	7,335	1,588	8,923

After adjusting all of the stranding dates for each run of the simulation r, we recompute this table with the generated x_r, which is the number of date-adjusted strandings that coincide with Navy exercise periods. Then, from each table, we compute an odds ratio—OR(u_r)—the ratio of odds of a whale stranding during the Navy exercise period, to the odds of a whale stranding outside of Navy exercise periods. We repeat the simulation 1,000 times, so we have a total of 1,000 values for the odds ratio of interest. From these results, we also can examine the variability of these odds ratios.

For calculations of the effect, we turn to the log odds ratio because of its nicer statistical properties. Recall that the hypothesis of no effect of Navy exercises on the whale strandings corresponds to the odds ratio of 1, or log odds ratio of 0. Based on the simulation results, we will be able to construct CIs for the odds ratio of interest.

Results

Figure 2 shows a timeline of strandings for all species at latitudes 34° N and below along with Navy exercises. We use 34° latitude S to the border with Mexico to approximate the Navy's southern California training area (U.S. DoN, 2005). The blue bars indicate the times of Navy exercises, and the tick marks indicate stranding events. The stranding tick marks shown on this slide represent the time the stranding was observed—not necessarily the time the stranding occurred. The times between stranding events showed an exponential distribution, allowing us to treat the strandings as independent events. We seek to address the following question: Does the pattern of strandings and Navy exercises indicate a correlation between Navy exercises and strandings when the stranding dates are adjusted as described above?

Seasonality of Strandings

Before performing any correlation calculations, we had to check for seasonality of the strandings, notably for gray whales (*Eschrichtius robustus*), which make their seasonal migration past southern California in the winter months. Figure 3 shows the number of strandings in our data, per month, with gray whales separated because they occur throughout the year but dominate the stranding data from January through April.

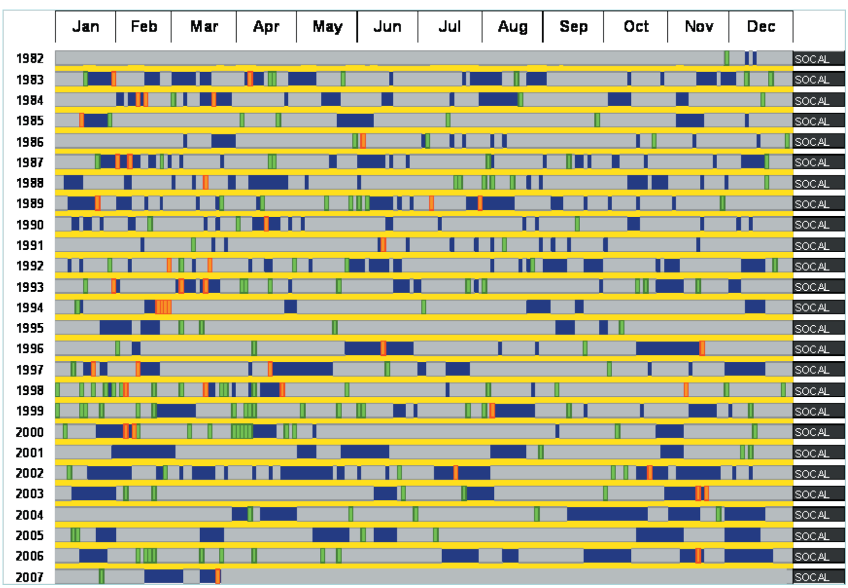

Figure 2. Timeline of southern California strandings and Navy exercises; blue bars indicate Navy exercise periods, and vertical tick marks indicate observation dates of strandings and are colored green if they do not overlay a Navy exercise and red if they do.

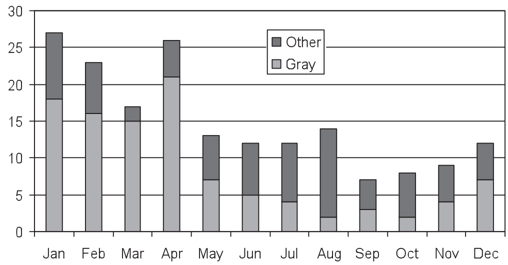

Figure 3. Southern California strandings by month, gray whales and all others

We compared the months January through April with the period of May through December and looked for differences in the stranding rates for gray whales. Table 3 shows the results. For the months of May through December, the average (over the years) stranding rate for gray whales is about 0.18 strandings per month. For the months of January through April, the average stranding rate ranges between 0.692 and 1 stranding per month. The differences in average stranding rates indicate seasonality for gray whale strandings. To account for the seasonality introduced by the gray whale winter migration, we performed two separate correlation analyses: (1) gray whales during the period January through April and (2) all other whales for the entire year.

Table 3. Test for seasonality in gray whale strandings

Month	Average stranding rate (Strandings per month)
January	0.769
February	0.731
March	0.692
April	1.000
May-December	0.180

Correlation Results: Strandings Excluding Gray Whale

We correlated non-gray whale strandings with exercises by removing gray whales from the stranding data. This resulted in 76 strandings over the 8,923-d period, with 1,588 d of sonar use. Figure 4 shows the distribution of the number of coincident strandings actually observed (obtained by adjusting the stranding observation dates as discussed above) from 1,000 iterations with our model. Fourteen, 13, and 12 were the most frequently observed numbers of coincident strandings. The average log odds ratio of a whale stranding coincident with Navy exercises to that in absence of Navy exercises was -0.00114, which is very close to zero. To create CIs, we used the SD from our simulation results. The resulting 95% CI for the log odds ratio was (-0.334, 0.332), which corresponds to the 95% CI for the odds ratio to be (0.716, 1.394). Because the first interval contains zero and the second contains 1, our results are consistent with the null hypothesis that Navy exercises and strandings are not correlated. It is important to note, however, that due to the small number of strandings overall, our estimate is quite variable, and the CI is wide.

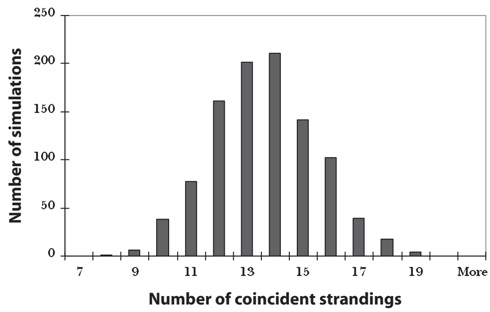

Figure 4. Model results, non-gray whales; number of strandings coincident with Navy exercises, 1,000 iterations

Correlation Results: Gray Whale Strandings

We performed a similar analysis for gray whales only for the months January through April. This resulted in 70 strandings over 2,968 d, with 590 d of sonar use. Again, if there were no relationship between exercises and strandings, we would expect the odds ratio to be close to 1 and the log odds ratio to be close to zero. Figure 5 shows the distribution of the number of coincident strandings actually observed (obtained by adjusting the stranding observation dates as discussed above) from 1,000 iterations with our model. Sixteen, 15, and 17 were the most frequently observed numbers of coincident strandings. The mean log odds ratio of stranding during Navy exercises to odds of stranding without Navy exercises was estimated to be 0.1645 in 1,000 simulation runs. The resulting 95% CI for the log odds ratio was (-0.129, 0.458), and the 95% CI for the odds ratio was (0.879, 1.582). These intervals are consistent with the null hypothesis that Navy exercises and strandings are not correlated. Again, however, the intervals are quite wide, indicating the benefit of collecting more data.

Discussion

Using stranding data covering the period November 1982 through March 2007, our analysis found that the number of whale strandings coincident with Navy exercises in the southern California area are not significantly different from what would be expected by random chance. This might be interpreted as evidence for a lower risk

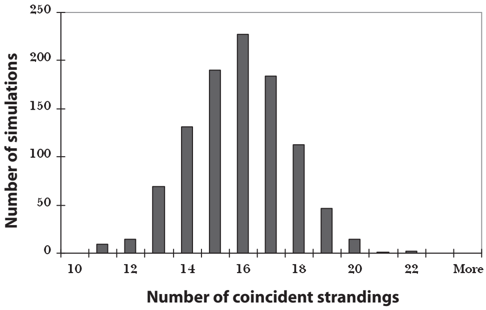

Figure 5. Model results, gray whales; number of strandings coincident with Navy exercises, 1,000 iterations

of sonar-related strandings for the majority of species. However, as mentioned in the introduction, the large number of single strandings known not to be related to sonar may make it more difficult to detect such a coincidence in a small number of cases. In addition, Filadelfo et al. (this issue) and D'Amico et al. (this issue) also indicated that no mass strandings of beaked whales have been reported in this area during this time period. It is therefore possible that some features of this area reduce the risk of sonar-related strandings. Several studies have investigated environmental contexts in the best studied cases of sonar-related mass strandings of beaked whales. Evans & England (2001) state,

> From the coincidence of strandings and sonar use in both time and geography, and from the nature of the observed physiological effects, the investigation team concludes that tactical mid-range frequency sonars aboard U.S. Navy ships were the most plausible sound source involved in this stranding. However, this sound source acted within a set of environmental factors that included the sound propagation characteristics present at the time, the underwater bathymetry, a constricted channel with limited egress avenues, and the presence of beaked whales that appear to be sensitive to the frequencies projected by tactical mid-range frequency sonar. Focusing on the interplay between the sound source and these environmental factors is much more likely to reduce future strandings than focusing on the sound source as the sole cause. (p. 38)

D'Spain et al. (2006) state,

> The acoustic sources in all three cases moved at speeds of 5 knots or greater and generated periodic sequences of high amplitude, transient pulses 15-60s apart that contained significant energy in the 1-10kHz frequency band. The environmental conditions included water depths exceeding 1km close to land. In addition, the depth dependence of the ocean sound speed created an acoustic waveguide whose [sic] lower boundary was formed by refraction within the water column. The anthropogenic sources in all cases were located within such waveguides. Under these conditions, sound levels decrease more slowly with increasing range after a certain transition range than otherwise, due to sound focusing and to decreased attenuation because of isolation over extended ranges from the ocean bottom. In addition, the frequency dispersion is such that pulses tend to remain as pulses during propagation. (p. 223)

This makes it difficult to conclude whether the lack of correlation between single strandings and sonar exercises in southern Californian waters is a consequence of a lower risk for the other species studied or a lower risk for all species due to the environmental conditions off southern California compared to the sites for which there is a significant correlation between sonar use and mass strandings of beaked whales.

Acknowledgments

We thank Mr. Joe Cordero of the National Oceanic and Atmospheric Administration, Long Beach, California, for his time, advice, and for making the California stranding database available to us. Tyack would like to acknowledge support from the U.S. Office of Naval Research and the Strategic Environmental Research and Development Program.

Literature Cited

Cox, T. M., Ragen, T. J., Read, A. J., Vos, E., Baird, R. W., Balcomb, K., et al. (2006). Understanding the impacts of anthropogenic sound on beaked whales. *Journal of Cetacean Research and Management*, *7*, 177-187.

D'Amico, A., Gisiner, R. C., Ketten, D. R., Hammock, J. A., Johnson, C., Tyack, P. L., et al. (2009). Beaked whale strandings and naval exercises. *Aquatic Mammals*, *35*(4), 452-472.

D'Spain, G. A., D'Amico, A. D., & Fromm, D. (2006). Properties of underwater sound fields during some well documented beaked whale mass strandings. *Journal of Cetacean Research and Management*, *7*, 223-238.

Evans, D. L., & England, G. (2001). *Joint interim report: Bahamas marine mammal stranding event of 15-16 March 2000*. Retrieved 3 December 2009 from www.nmfs.noaa.gov/pr/pdfs/health/stranding_bahamas2000.pdf.

Filadelfo, R., Mintz, J., Michlovich, E., D'Amico, A. D., Tyack, P. L., & Ketten, D. R. (2009). Correlating military sonar use with beaked whale mass strandings: What do the historical data show? *Aquatic Mammals*, *35*(4), 435-444.

Freitas, L. (2004, March). The stranding of three Cuvier's beaked whales *Ziphius cavirostris* in Madeira Archipelago–May 2000. *European Cetacean Society Newsletter*, *42*(Special Issue), 28-32.

Global Security. (2009). *Southern California Offshore Range (SCORE).* Retrieved 3 December 2009 from www.globalsecurity.org/military/facility/score.htm.

U.S. Department of the Navy (U.S. DoN). (2005). *Marine resources assessment for the southern California operating area.* Plano, TX: Geo-Marine, Inc.