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Sonar Use and Beaked-Whale Strandings

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1

This briefing documents the results of a study CNA performed, in conjunction with SPAWAR Systems Center San Diego (SSC-SD), on the correlation between naval sonar use and beaked-whale mass strandings. It was performed at the request of the Deputy Chief of Naval Operations, Logistics (OPNAV N4).

Background

- Do Navy sonars cause beaked-whale mass strandings?
  - A few mass strandings[a] when Navy ships are near....
    - But strandings often occur naturally for a variety of reasons...
- Previous analyses
  - Individual events
    - Bahamas 2000; Madeira 2000; Canaries 2002; Greece 1996
      - Frantzis (1998; 2004); D'Amico, Ed. (1998); Evans and England (2000); Fretias (2004); Martin et al. (2004)
  - Very limited data
  - No overall statistical analyses
    - Exposure with no observed response
- Current study
  - Entire distributions vs. individual events
  - Objective statistical treatment

a. A mass stranding is defined as 2 or more animals, not a mother/calf pair [1].

2

Marine mammals routinely strand in the shallow waters along U.S. shore lines and in many other parts of the world. In most cases, the cause of strandings is unknown; some identified causes include disease, parasite infestation, harmful algal blooms, injuries from ship strikes or fishery entanglements, and exposure to pollution, trauma, and starvation. There have been a handful of incidents when Navy sonar operations at sea coincided in time and location with the mass stranding of beaked whales. A research active source that had both a low- and mid-frequency aperture was used during the NATO sea trial that seemed to coincide with the 1996 mass stranding off the coast of Greece. Although a conclusive "cause and effect" relationship has not been generally established, there is anecdotal evidence and scientific concern that military sonars could cause beaked whales to strand [2 through 10].

Most previous attempts to determine whether correlations exist between military sonar use and beaked whale strandings have looked at individual events and pointed out those instances in which military operations seemed to coincide in time and location with a beaked whale mass stranding. Lacking reliable data on naval operations, looking for temporal-spatial correlations has been the only method available to us prior to this study. A retrospective analysis was suggested as the outcome of the MMC Beaked Whale Workshop, April 2004 [11] and in [12].

The Navy asked CNA to perform a study of this type.

Background (Cont'd)

- Do Navy sonars cause beaked-whale mass strandings?
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    - But strandings often occur naturally for a variety of reasons...
- Previous analyses
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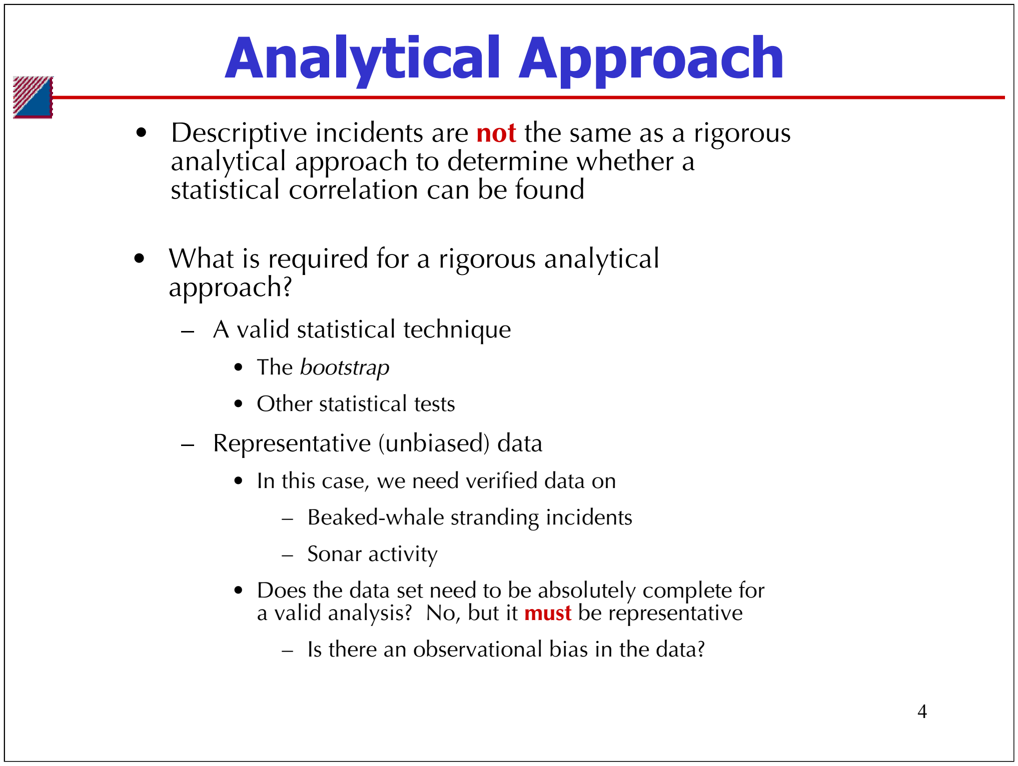
  - Entire distributions vs. individual events
  - Objective statistical treatment

3

Working with the OPNAV N45 staff, we were then tasked to specifically examine the correlation between mid-frequency sonar use and beaked-whale mass strandings. SSC-SD, the co-investigator on this study, has collected supporting beaked-whale stranding data and has performed a literature search from publicly available sources regarding naval operations.

ONR had funded SSC-SD several years ago to begin developing a global beaked-whale stranding database and to look at publicly available sources for information on naval operations, as described in [13]. (The SSC-SD beaked-whale stranding database is unpublished and still being verified and validated). It is that work that we have built upon in this study.



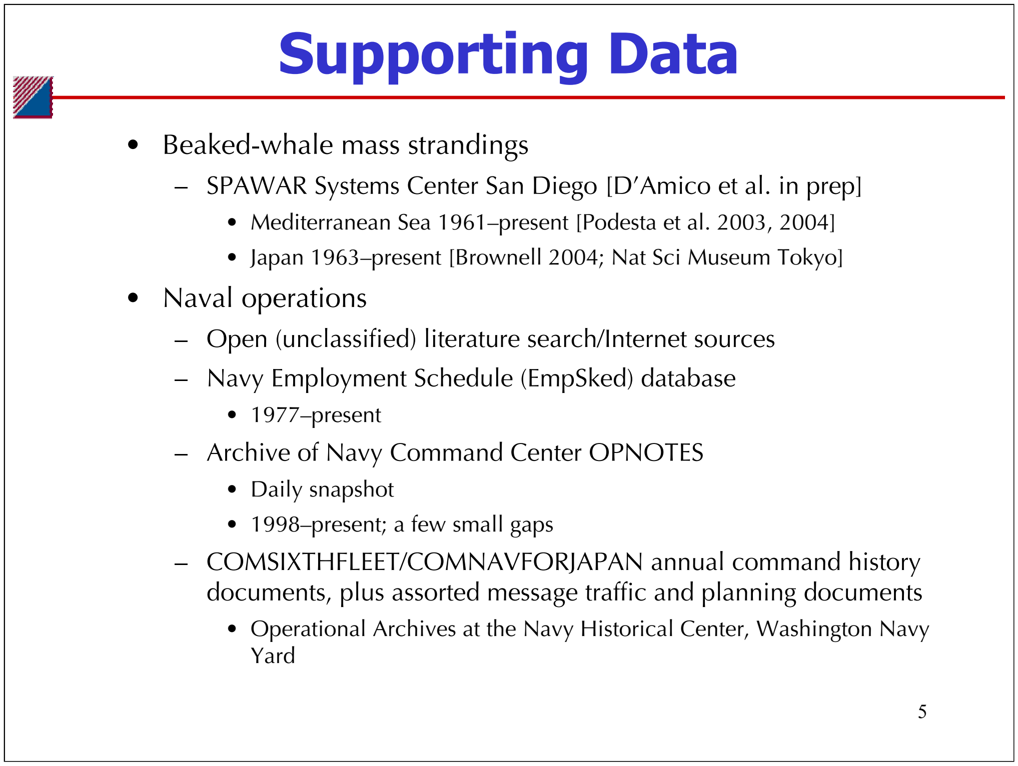
The anecdotal looks that have been performed in the past have usually counted only the number of instances in which strandings and military operations seemed to coincide. They have not examined the important related question of how many times military operations took place without any observed impact on whales. Among the first to address this important issue was D'Amico et al. (in prep). Based on their work, we attempt here an objective statistical treatment.

An objective analysis of this type requires a valid statistical technique and representative samples of naval operations and beaked whale strandings.

For our statistical analyses, we use a bootstrap method [14] and other standard statistical tests of proportions.

A crucial point regarding the data needs of a study such as this one is that the data sets for both whale strandings and naval operations do not have to be complete; in fact, we are quite certain that we have not captured every beaked-whale stranding event or naval operation that took place in the regions we studied. However, the data must be unbiased. For example, if whale stranding networks focused all their data gathering effort on times and locations of naval operations, a biased sample would result. Or, if we looked only at naval exercises in areas where we knew stranding observations were not made, a bias the other way would result. We have no reason to believe that our data suffer from biases in either direction.

We list our data sources on the next slide.



SSC-SD compiled data on beaked-whale mass strandings. This data set included strandings in the Mediterranean Sea [13, 15, 16] from 1961 to 2004 and around Japan [12, 17] from 1963 to 2004. We chose these data sets because they are relatively complete and well documented.[1] They are sites that have been the subject of prior scientific and public discussion with respect to sonar-related beaked-whale strandings. There are other sites of interest in this regard that have not been subjected to the same statistical analyses.

We compiled data on naval operations from various sources. SSC-SD compiled data from an unclassified literature/Internet search. We supplemented these data with information from the various classified sources shown on this slide.

We searched the Navy's Employment Schedule Database [18], resident here at CNA. These data cover the period from 1977 to the present. To identify events in which mid-frequency sonar was likely used, we extracted all records for underway Cruiser-Destroyer (CRUDES) ships in which the activity field indicated likely anti-submarine warfare (ASW) operations and sonar use (ASWEX, COMPTUEX, FleetEx, etc.). In nearly all cases, the naval operations data used in this study did not allow us to determine the specific times or total amount of time active sonar was in use. In fact, one could say we can't really be certain that sonar was in fact used at all in any particular exercise. However, for the purposes of a high-level correlation analysis, our assumption that an "ASW Exercise" or a "Multiwarfare Exercise" involving CRUDES and submarines probably involved active sonar use is reasonable. Detailed reconstruction of the interaction of Navy vessels and beaked whales during particular events was not the goal of this study.

1. See [13] for a complete discussion of this dataset, including the geographic distribution of strandings in these two areas.

Supporting Data (Cont'd)

- Beaked-whale mass strandings
  - SPAWAR Systems Center San Diego [D'Amico et al. in prep]
    - Mediterranean Sea 1961–present [Podesta et al. 2003, 2004]
    - Japan 1963–present [Brownell 2004; Nat Sci Museum Tokyo]
- Naval operations
  - Open (unclassified) literature search/Internet sources
  - Navy Employment Schedule (EmpSked) database
    - 1977–present
  - Archive of Navy Command Center OPNOTES
    - Daily snapshot
    - 1998–present; a few small gaps
  - COMSIXTHFLEET/COMNAVFORJAPAN annual command history documents, plus assorted message traffic and planning documents
    - Operational Archives at the Navy Historical Center, Washington Navy Yard

6

We reviewed the archive of the Navy Command Center's daily OPNOTES; CNA archives these daily summaries of worldwide Navy operations for the Navy Command Center in the Pentagon. These data covered the period from 1998 to the present, with a 3-month gap in 1998 and a 5-month gap in 2001. We obtained further details on many exercises from the COMSIXFLEET Mediterranean Exercise Manual [19].

We also visited the Operational Archive maintained by the Navy Historical Center at the Washington Navy Yard. We reviewed the annual command history documents for COMSIXTHFLEET and COMNAVFORJAPAN, plus various related message traffic and planning documents. This involved a hand search through many boxes of papers and documents; although these records go back to the 1940s or earlier, many years were missing from this dataset. For the years in which command history and related documents were available, the information on naval exercises was very complete.

Our data on naval operations for the Mediterranean and Japan include exercises led by allied navies (for example, NATO exercises in the Mediterranean and Japanese or Korean exercises around Japan). However, because we gathered this information from U.S. Navy records, our data are skewed toward U.S. naval events, and we likely missed many allied exercises in which there was no U.S. involvement. Because we compare stranding *rates* during sonar and non-sonar periods, this over-representation of U.S. operations does not introduce a bias.

A few important points regarding the naval operations data we used in this study must be kept in mind.

Supporting Data (Cont'd)

- Beaked-whale mass strandings
  - SPAWAR Systems Center San Diego [D'Amico et al. in prep]
    - Mediterranean Sea 1961–present [Podesta et al. 2003, 2004]
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7

We tried to include only those exercises in which mid-frequency sonar was likely to have been used, based on exercise descriptions and participants. However, we did not reconstruct these exercises down to the level of ship-tracks and timelines to determine exactly when and where (within the overall exercise area) sonar was used. Analyses of that type would be a useful follow-on to this study if the required information is available. Those types of detailed reconstructions would be useful in establishing definitive cause-effect relationships. Our mission was to look for high-level correlations, to help suggest areas in which further work is warranted.

For the most part, we only include major (multi-ship) exercises. Correlations between beaked whale strandings and exercises of this type may not be applicable to "all sonar use" (i.e., single ship events). Thus, the correlation analyses done here represent a "tough" test for naval sonars.

Outline

- Introduction
  - Background
  - Approach
  - Data
- Findings
  - Mediterranean Sea
  - Japan
  - Discussion of causative factors
- Summary

8

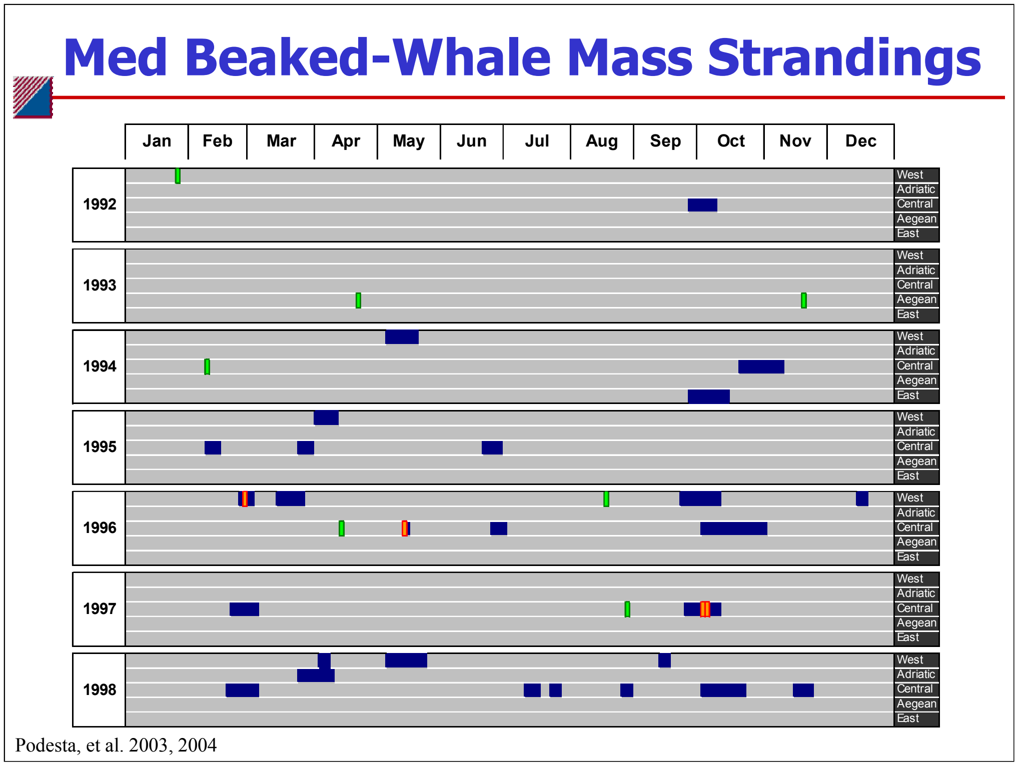
We will now look at correlations between naval operations in which sonar was likely to have been used, and beaked-whale mass strandings in the Mediterranean Sea and around Japan. Specifically, we will examine the difference in stranding rates between periods when sonar events are taking place and periods when they are not.

We will first look at the Mediterranean.

Area of Study: Mediterranean

9

We divided the Mediterranean into the five regions shown on this slide.

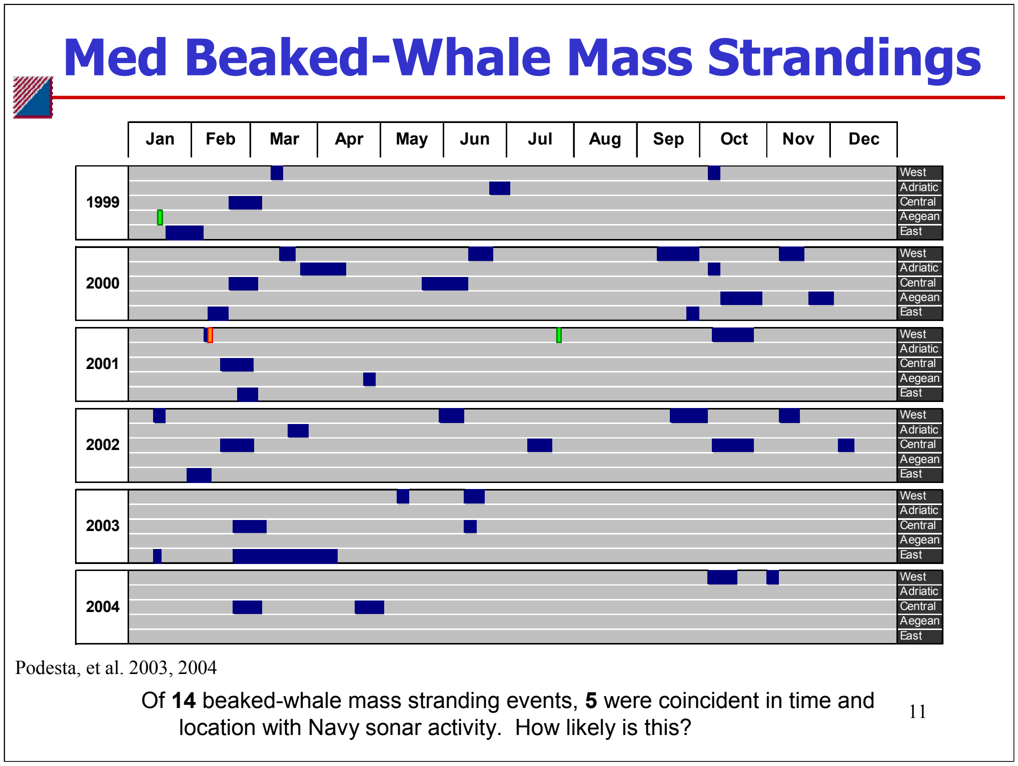


This slide and the one that follows show the periods of naval activity (blue bars) and times of beaked-whale mass strandings (red and green lines) in each of the five regions of the Mediterranean [15]. The green lines indicate strandings that did not coincide with naval activity; the red lines indicate strandings that did. All the stranding events shown on this figure were the beaked-whale species ziphius cavirostris (Zc)—Cuvier's Beaked Whales, because this is the beaked whale commonly found in the Mediterranean.

Overall, of the 14 beaked-whale mass strandings observed in the Mediterranean Sea from 1992 to 2004, 5 are known to have coincided with naval operations. The 5 that coincided with naval operations were:

- The stranding on 25 February 1996 in the Gulf of Valencia; it coincided with exercise SHAREM-114 [13].
- The stranding on 12 May 1996 on the west coast of Greece; it coincided with the sonar R&D event "SWAC-4" in which a mid- and low-frequency acoustic source was towed at a depth of 86 meters [8, 10].
- The strandings on 2 and 3 October 1997 were on the west coast of Greece; they coincided with the exercise Dynamic Mix-97 [9].
- The stranding on 7 February 2001 on the coast of Algeria; it coincided with exercise Algerian USWEX.

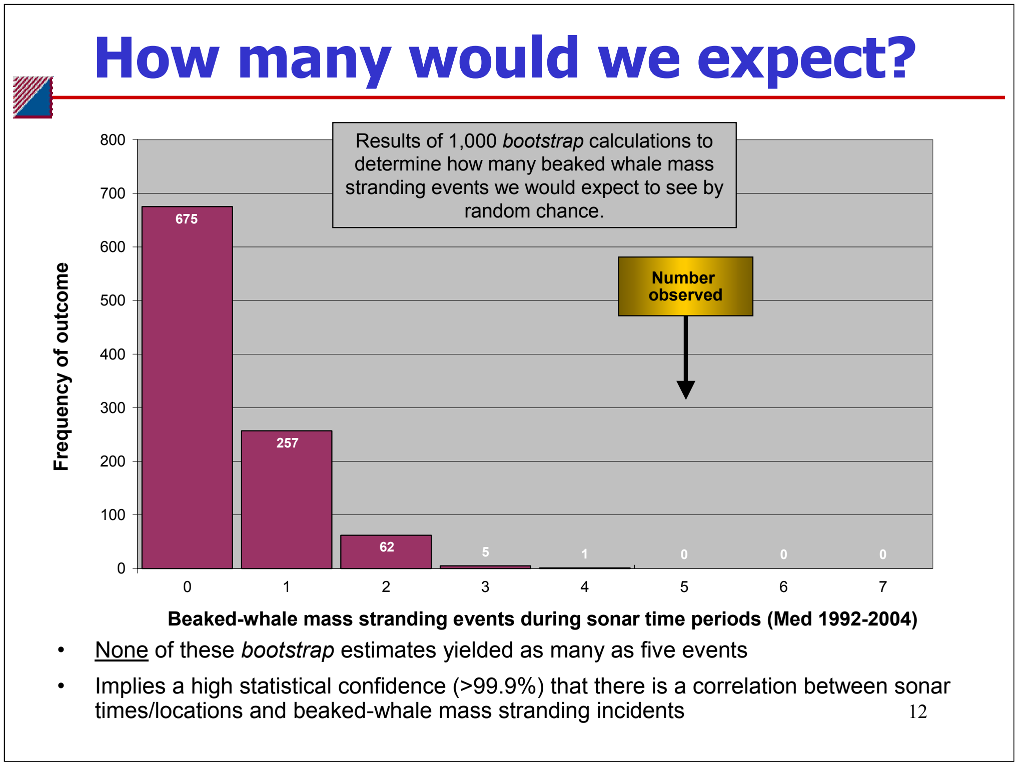
Note that two of the beaked-whale mass stranding occurred within 1 day and about 60 miles of each other. We decided to count this as two events to be consistent with the definitions in D'Amico (1998) [13]. Counting this as a single event did not change the overall results of our statistical analyses.



What are the implications of 5 of the 14 beaked-whale mass stranding events coinciding with naval operations? Specifically, how likely would this result be if the "sonar" times indicated were no different than the non-sonar times with respect to beaked whale strandings?

To address this question, we turn to an analytical technique known as the *bootstrap* [14]. The bootstrap technique allows us to use the stranding data distribution during the non-sonar times as a "template" for estimating the numbers of strandings we would be likely to see during sonar times if stranding occurrences during sonar times followed the same underlying distribution as the strandings during non-sonar times.

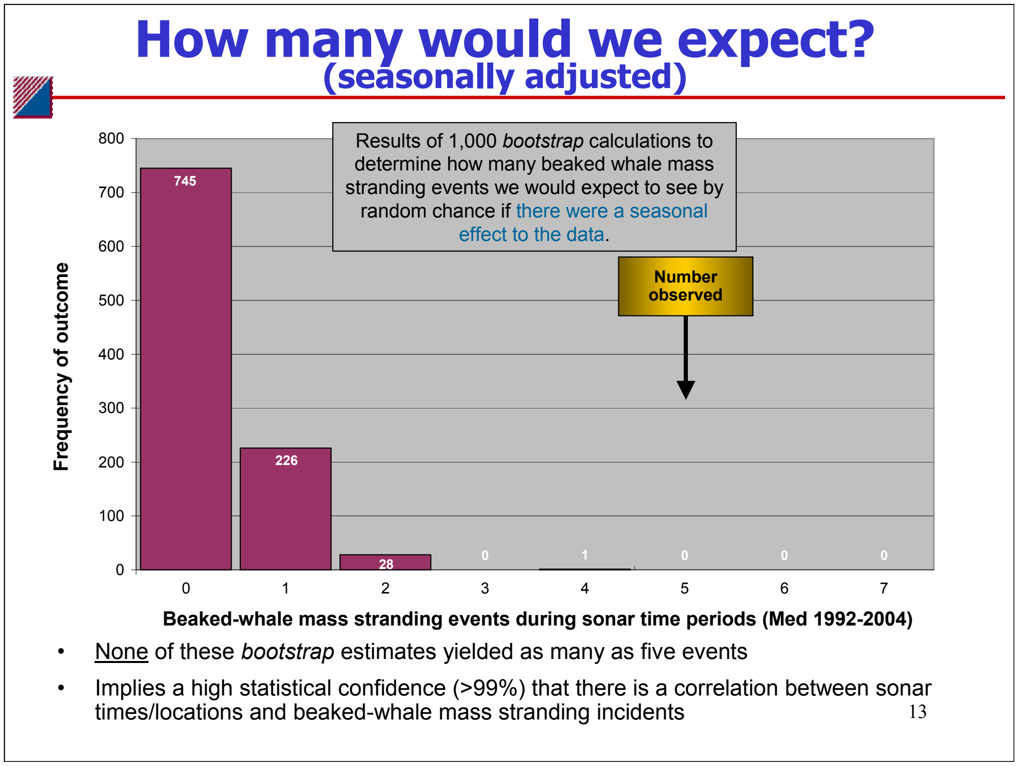
In practice, we apply this "template" by repopulating the sonar days with the non-sonar stranding data distribution. This is accomplished by first blanking out (i.e., deleting) the stranding data for all days labeled as "sonar," then filling each of those days back in by randomly sampling from the days labeled as "non-sonar." This results in an estimate for the number of strandings expected during sonar times in the absence of a correlation between strandings and sonar. This process is then repeated many times to develop a distribution of such estimates. This distribution can then be compared to the number of strandings actually observed. The expected value of this distribution is a reflection of the stranding rate during the non-sonar periods. The value of the bootstrap is that it is non-parametric, and it shows the sampling distribution around this expected value, allowing the determination of the significance of any observation. It also lets us examine seasonal effects.



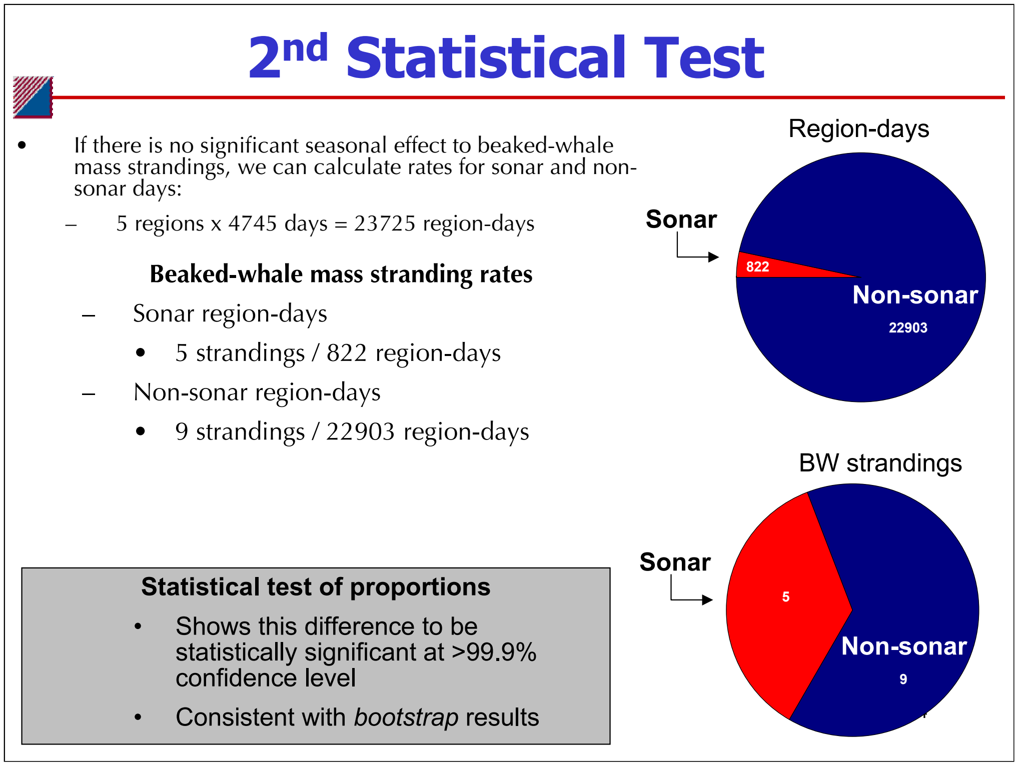
We will first perform a non-seasonally adjusted calculation.

The histogram summarizes the results of the non-seasonally adjusted bootstrap analysis. We performed 1,000 iterations of the bootstrap calculation. Along the x-axis is the number of beaked-whale mass strandings estimated; along the y-axis is the number of times a particular estimate was obtained.

The results show that if the sonar times are no different from the non-sonar times with respect to beaked-whale mass strandings, then you would most often see just zero or one beaked-whale mass strandings during the sonar times in question. Occasionally, you would see two, but rarely more than that. None of the results approached the actual number of beaked-whale mass strandings observed (which was five). We therefore infer from this analysis that there is a correlation between sonar time periods and an increased incidence of beaked-whale mass strandings. The confidence level we impute for this correlation, given that none of the 1,000 iterations equaled or exceeded the observed number of strandings, is greater than 99 percent. Of course, this correlation does not imply that sonar operations "usually" cause beaked whales to strand. The great majority of sonar operations have no coincident beaked whale strandings



An additional variation on our analysis stems from the question of whether there is a seasonal effect in the natural background of beaked whale strandings. If there is, then we can account for that effect in our bootstrap analysis by sampling only within a certain period of time (we chose 30 days) of the data point in question when we do our "re-populating" of the data for the sonar days. For example, beaked whales might be closer to shore during certain times of the year and thus more likely to strand. We performed this analysis as an added check, although we observed no seasonal trend in the beaked-whale mass stranding data used in this study. The histogram above shows results for this modified bootstrap. As we can see, the results quoted on the previous slide are unaffected.



In addition to the bootstrap analyses, we performed a standard test of proportions on the difference in stranding rates between the times sonar activity was occurring and was not occurring.

By dividing the Mediterranean into five regions, we obtained 23,725 (13 years x 365 days/year x 5 regions) region-days from 1992 to 2004. For the sonar periods, we observed 5 beaked-whale mass strandings during the 822 region-days of sonar activity. For the non-sonar periods, we observed 9 beaked-whale mass strandings during the 22,903 region-days of non-sonar activity. Thus, we have a much greater stranding rate during the sonar periods (5/822 > 9/22,903). The pie-charts on the right show this graphically: The fraction of beaked-whale mass strandings that occur during sonar periods is much greater than would be expected based on the fraction of time that sonar activity is occurring.

How significant is this difference in beaked-whale mass stranding rates? A statistical test of proportions shows it to be significant at the .999 level. (This means that there is less than a 1 in 1,000 chance that random (sampling) variability would have yielded a difference this big if there were no actual difference in the beaked-whale mass stranding rates between the sonar and non-sonar periods.

This result is very consistent with the bootstrap results discussed previously. As noted previously, this fundamental result holds even if we count the two 1997 events in Greece as a single event.

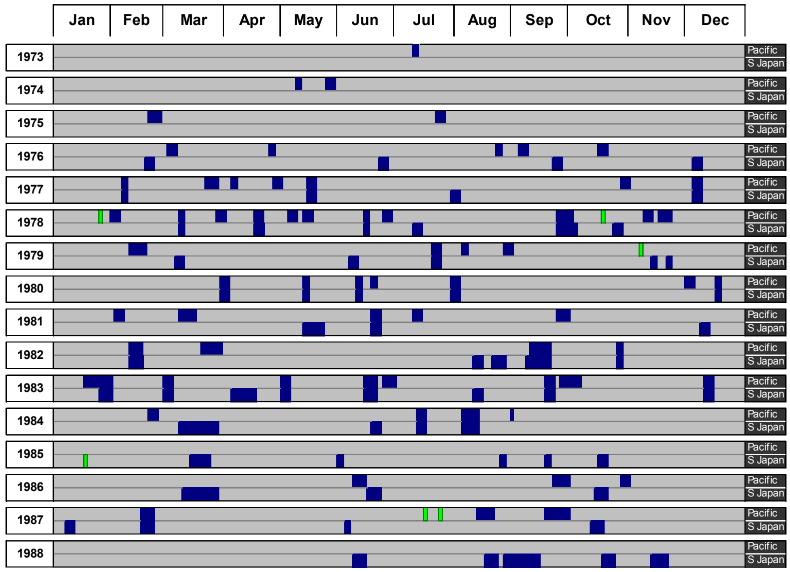
Area of Study: Japan

15

We will now look at beaked-whale mass strandings around Japan.

In this case, we divided the study area into just two geographic sectors—the Sea of Japan side and the Pacific side.

Beaked-Whale Mass Strandings Near Japan

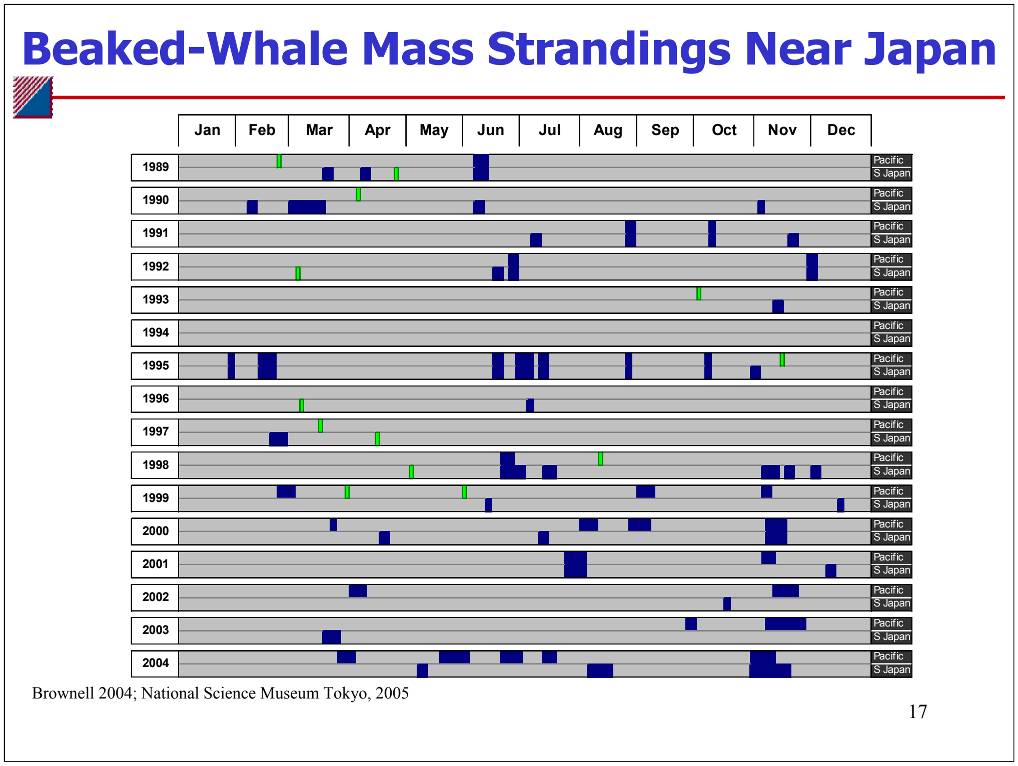


Brownell 2004; National Science Museum Tokyo, 2005

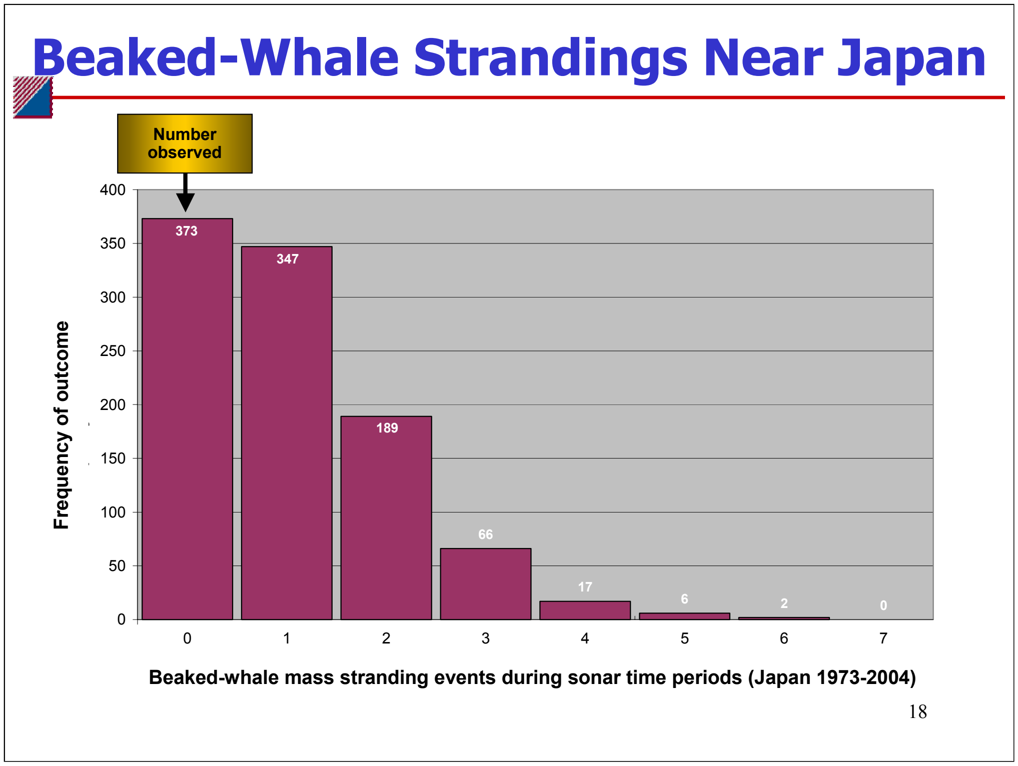
16

This and the following slide show periods of sonar activity and beaked-whale mass stranding events over the 32-year period from 1973 to 2004. Both Zc and mesoplodon spp strandings occur around Japan.

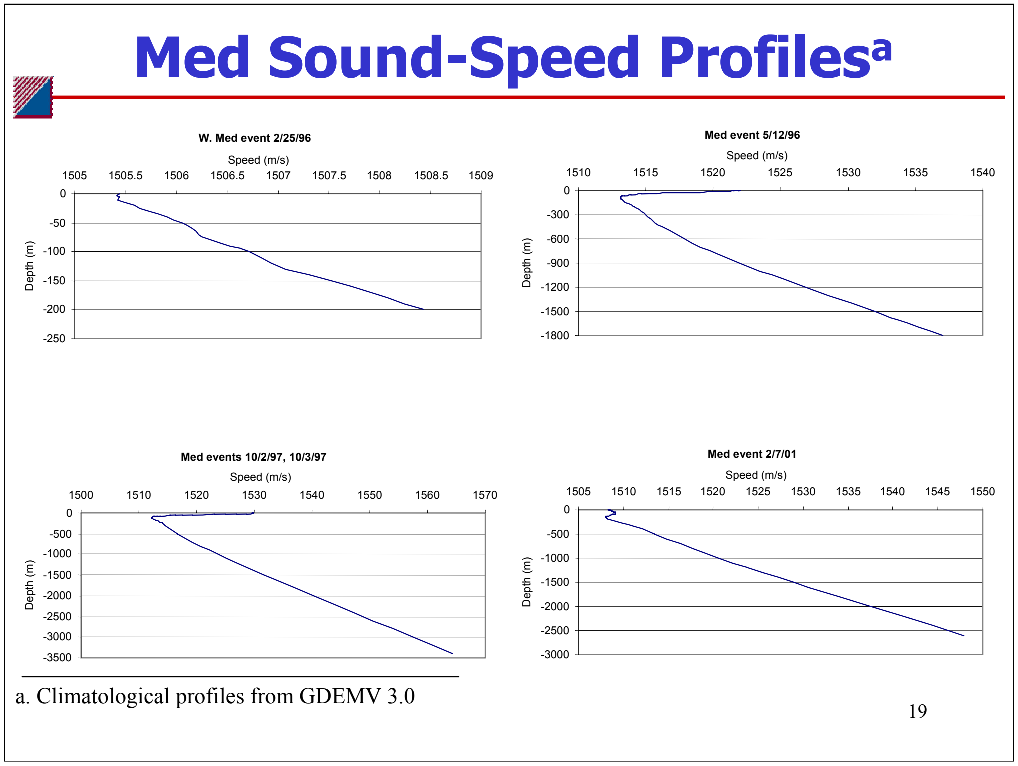
No beaked-whale mass stranding events coincided with periods of naval activity. Brownell et al. [12] hypothesized a possible link between Zc mass strandings on the central Pacific coast of Honshu and U.S. Navy sonar activity, based on limited information on naval operations. They noted that many more beaked-whale mass strandings have been observed in the water near Japan that is frequented by U.S. naval forces, compared to an oceanographically similar region off New Zealand where military sonar is almost never used. They note the need for further analysis using more detailed data on naval operations. Our results in this case are not consistent with the link hypothesized by Brownell.



This is a continuation of the previous slide; it shows the years 1989–2004.



As with the data from the Mediterranean, we performed our bootstrap analysis on the data on the waters near Japan. As before, the resulting histogram, shown above, illustrates the distribution in beaked-whale mass strandings that we would expect if sonar times and non-sonar times were no different with respect to strandings. Unlike the Mediterranean data, however, because the number of strandings is 0, there is no possibility of finding a statistically significant correlation between beaked-whale mass strandings and sonar here. (The above histogram is generated using the modified bootstrap that accounts, as explained earlier, for any seasonal effect in the stranding data.)



Our analysis of the Mediterranean showed a highly significant correlation between naval sonar activity and beaked-whale strandings, but our analysis of the waters around Japan showed no correlation. So what are we to conclude?

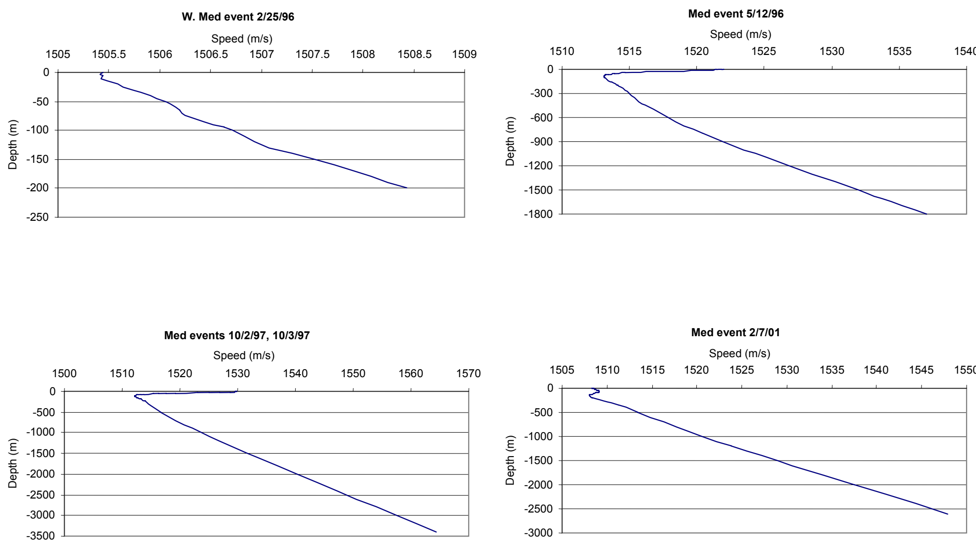
Several scientists believe that a confluence of factors can lead to military sonars causing beaked whales to strand. Environmental factors such as ducting [2, 21] and/or reverberation [22] may contribute to this confluence of factors suggested in [2, 6, 20, 21].

D'Spain et al. (in press) suggests the presence of an acoustic channel for the beaked-whale mass stranding events that occurred in the Bahamas and Greece. Propagation path was one factor we were able to readily examine here. On this slide, we show climatological sound-speed profiles for the dates and locations of the five coincident beaked-whale mass stranding events in the Mediterranean. We obtained sound-speed profiles from the Navy's Generalized Digital Environmental Model (GDEM) version 3.0 [23]. GDEM provides climatological profiles based on aggregates of several observations. Profiles at the times of the events listed on this slide could vary from the monthly climatological profiles shown here.

The event on 25 February 1996 occurred in the western Mediterranean off the coast of Spain. Acoustic conditions in this case are upward refracting (half channel).

The beaked-whale stranding event of 12 May 1996 off the coast of Greece in the central Mediterranean coincided with the testing of a towed source at a depth of 86 meters. Acoustic conditions in this case show strong duct for the source at 86 meters, with the source being right at the axis of the duct [10].

Med Sound-Speed Profiles[a] (Cont'd)



a. Climatological profiles from GDEMV 3.0

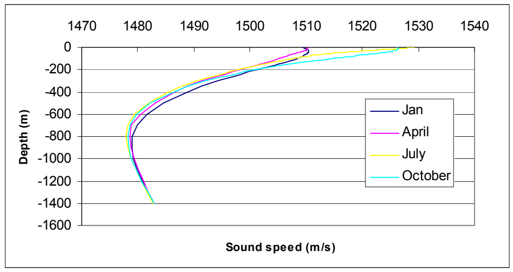
20

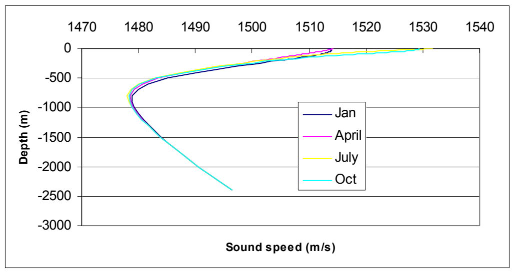
Acoustic conditions for the beaked-whale mass stranding events of 2 and 3 October 1997 off the coast of Greece show strong convergence zone (CZ) propagation for a source at a depth of 8 meters (the depth of a ship hull sonar).

Sonar operating guidelines [24] state that for the SQS-53C sonar, an increased data rate (a two- or three-fold increase) can be used for CZ propagation paths, whereby the sonar emits two or three times as many pings over a given time interval.

Acoustic conditions for the 7 February 2001 stranding event off the coast of Africa also support long-range propagation. A weak layer exists down to 55 meters. Below this layer, strong half-channel (upward refracting) conditions exist.

Sound-Speed Profiles Near Japan[a]





a. Climatological profiles from GDEMV 3.0

21

Most of the beaked-whale mass strandings in our data set were clustered in and around Sagami Bay, off the central Pacific coast of Honshu. Here we show climatological sound-speed profiles for two areas off of Japan for all four seasons. The top figure shows profiles for a position in central Sagami Bay (35-00N/135-30E); the bottom figure shows profiles for an open-ocean location outside the Bay (34-39N/139-56E).

Both locations are generally downward refracting for a source at a depth of about 25 feet, for all four seasons. For the Sagami Bay site, rays down to 1.6 degrees will be ducted down to 30 meters in January and rays down 0.5 degrees will be ducted down to 10 meters in October; for the open-ocean site, rays down to 0.85 degrees will be ducted down to 20 meters in January and rays down 0.25 degrees will be ducted down to 10 meters in October. Specific conditions could of course vary from site to site or over time.

Fromm and McEachern (2000) [22] have looked at reverberation conditions and their possible link to beaked whale strandings. They found that reverberation is among a number of other variables that have been suggested as possibly affecting the tendency of the beaked whales to strand. These variables have not been analyzed in this study, so they cannot be ruled out as contributing as much or more to the likelihood of stranding as ocean sound-speed profiles.

Outline

- Introduction
  - Background
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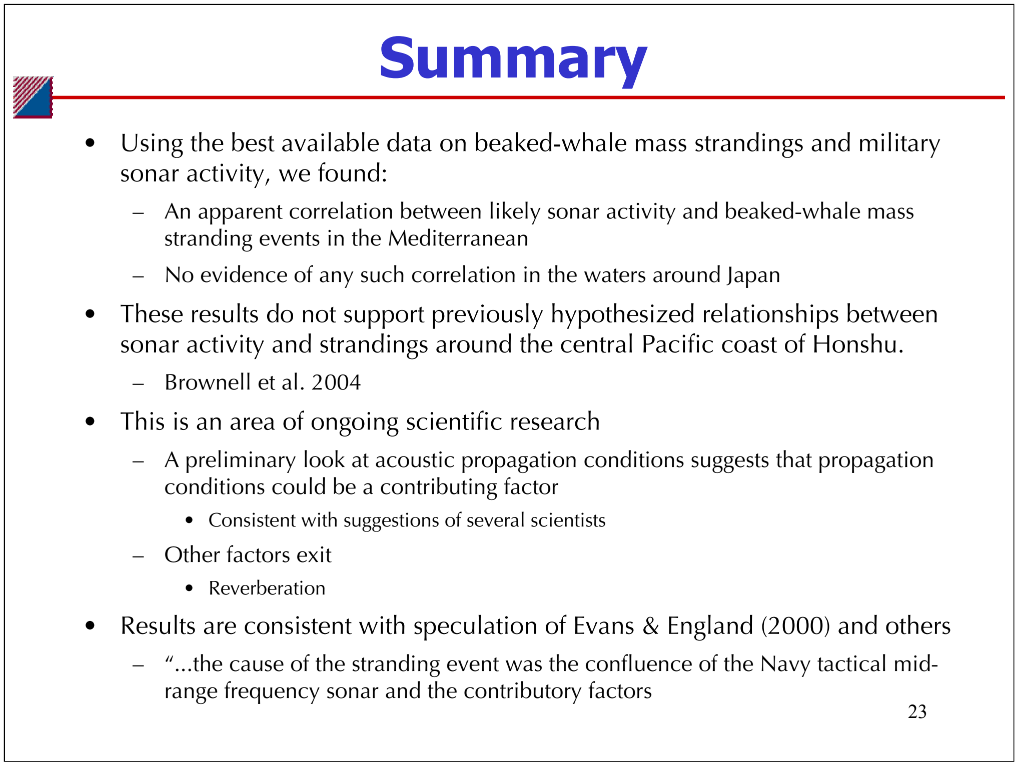
- Findings
  - Mediterranean Sea
  - Japan
  - Discussion of causative factors
- Summary

22

We will now summarize.



Using the best available information on beaked-whale mass strandings in the Mediterranean Sea and around Japan, and an objective compilation of information on naval operations from both open and classified sources, we found a correlation between likely sonar activity and beaked-whale mass strandings in the Mediterranean but no correlation in the waters around Japan.

Our results are inconsistent with the recently suggested hypothesized link between beaked-whale mass strandings around the central Pacific coast off Honshu and U.S. Navy operations.

The potential link between beaked-whale mass strandings during periods of sonar exercises and sound propagating conditions, revealed in our preliminary analysis, is consistent with prior suggestions of possible factors that might contribute to an increased likelihood of stranding. But this point needs further investigation, because 1) propagation is only one of several possible physical factors that could come into play, 2) average historical data may not in fact accurately represent the actual propagation conditions at the time and site of reported strandings, and 3) most sonar exercises result in NO stranding, including many times when there were likely to have been similar ducted propagation conditions, so propagation conditions alone are not a sufficient indicator of the conditions likely to result in stranding. Thus it appears that sonar may impact beaked whales only if the whales are in proximity and the necessary set of physical conditions is present.

We stress that propagation path is only one of several possible physical factors that could come into play. D'Amico et al. (in prep) and D'Spain et al. (2004) [13, 21] note that most of these strandings occur in regions of steep topography, so reverberation could be a contributing factor. Future analyses should look not only at individual factors but at the impact of combinations of factors, including geography, physical factors (acoustic conditions), and sonar use parameters.

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