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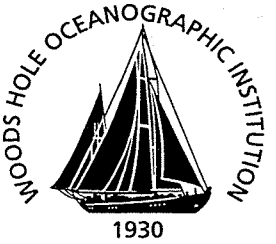

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Whale Call Data for the North Pacific November 1995 through July 1999 Occurrence of Calling Whales and Source Locations from SOSUS and Other Acoustic Systems

by

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February 2000

Technical Report

Funding was provided by the Office Naval Research under Grant No. N00014-96-1-1130, SERDP and CNO N45.

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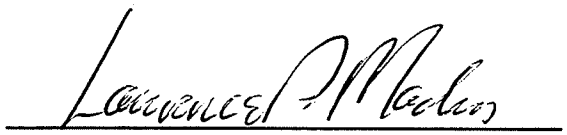

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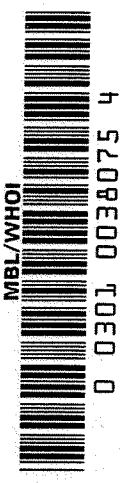

WHALE CALL DATA FOR THE NORTH PACIFIC

NOVEMBER 1995 THROUGH JULY 1999

OCCURRENCE OF CALLING WHALES AND SOURCE LOCATIONS

FROM SOSUS AND OTHER ACOUSTIC SYSTEMS

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ABSTRACT

Calls of blue whales (Balaenoptera musculus), fin whales (Balaenoptera physalus), and humpback whales (Megaptera novaeangliae) were identified in the data from U.S. Navy Sound Surveillance System (SOSUS) and other hydrophone arrays. These data on calling whales from November 1995 through July 1999 have been listed here for four offshore, deep-water Regions along continental margins of the North and Northeast Pacific. The occurrence of calling whales was monitored during two-day periods each week. Call data recorded from each array identified species, call occurrence, variation, received beam, and relative numbers of calling whales. This allowed assessment of seasonal distribution of calls for the different species, and provided locations for sources received at multiple arrays. Blue whale tonal sounds were distributed widely, received most in the NW Region, with a peak in occurrence in the fall. Fin whale "20-Hz" repetitive pulse sequences were received from whales grouped in local areas in all Regions, with a peak in occurrence in midwinter. Humpback songs were received from December through May particularly in the SE Region. The offshore listening systems allowed basin-wide monitoring of the seasonal distribution of these calling whales.

INTRODUCTION

Since 1958, beginning with early U.S. Navy hydrophone array installations, such as off Nantucket Is, MA, researchers from the Woods Hole Oceanographic Institution have used data from such arrays to observe and follow variations in calling by the different whale species. The level of Navy classification of information from these facilities prevented direct application of such data obtained from these arrays to the studies of whales at sea. However, it was possible to relate the occurrence of certain sounds to the presence of whales of particular species, and to confirm that the calling patterns observed from ships close to the whales could also be recognized on the standard Navy acoustic displays of their array data. Periodically, concentrations of the different whale species could be located in the areas indicated by the Navy arrays so the details of the whale acoustic behaviors could be studied from shipboard. Many of the early identifications of whale call repertoires, in fact, developed from the integration of observations of the sound patterns on the Navy acoustic displays with our ship-based studies of the whales at sea. These experiences provided confidence that the calls received by the Navy acoustic systems were indeed those of particular species of whales.

Therefore, as such data became available in recent years, not only from military but other systems as well, the Navy came to our aid, and programs were initiated to help Navy analysts identify biological noises. With the retirement from the Navy of some of these expert analysts, we began a systematic program, with their help, to monitor whale calls across the North Pacific Region. The whale call monitoring program was formally organized through SPAWAR (Dr. Dennis Conlon) in 1995, and the careful collection of whale call data has continued uninterrupted since November 1995.

Our previous experience with SOSUS and with the Navy acoustic processing systems had demonstrated that we could use unmodified Navy and other existing acoustic systems to recognize reliably particular whale call patterns from several whale species. It was important to impact Navy facilities as little as possible, and so organization of the data at Woods Hole was planned. A system was required that would allow monitoring of the acoustic data by analysts experienced in both recognition of whale calls and in operation of the Navy analytic systems. The call data needed to be recorded in unclass format, transferred without error to Woods Hole for organization into appropriate

database systems, and retrieved as needed for analysis of the seasonal occurrence of calling whales. These analyses could then be distributed as timely, updated information on the presence of calling whales in the North Pacific Regions.

These tasks have been accomplished. A very simple monitoring protocol and data recording techniques evolved which allowed appropriate handling of the call data and permitted wide flexibility in comparisons and analyses of the variations in distribution, movements, seasonality, and call repertoires of the different species.

METHODS

The acoustic data from offshore SOSUS and other hydrophone arrays in the North Pacific were monitored beginning in November 1995, and recognized whale calls were recorded and analyzed to describe their distribution and seasonality. Locations for many of the Navy hydrophone systems remain protected, as are their characteristics and associated data processing. The hydrophone arrays that were monitored were bottom mounted with a variety of sensor configurations. To provide comparable information from Navy and all other arrays, regardless of their composition, the beam-formed array data were interpolated to provide the equivalent of 40 line array beams for each array. Array orientations were not considered for these analyses. The occurrence of calling by whales was assessed from the beam-formed spectrographic data from ten arrays selected to provide representative coverage for four offshore Regions along the continental margins of the North Pacific. These offshore Regions were labeled NW, NC, NE, and SE, divided at increments of 30^{o} Longitude by 15^{o} Latitude (see map page 25). Some north-south detail was provided by the use of two or three arrays located at different latitudes within these Regions. Arrays in each Region were labeled from the north

(SE1 north of SE2 in SE Region, etc.). There was little overlap between Regions and even between arrays within Regions for the usual calling occurrence data. Two arrays were monitored in each of the NW and NC Regions and three (potentially one-third more observations) in the NE and SE Regions.

Arrays were monitored by analysts with extensive experience working with these Navy and other acoustic systems, as well as with the spectrographic display of beam-formed analyses of the whale calls. .Call identifications were reviewed regularly by WHOI researchers with 10 to 40 years experience with such sounds. The occurrence of calling by the different whale species was ascertained by visual scrutiny of spectrographic analyses of the acoustic data from all beams for each of the ten arrays. The data from these arrays were systematically examined over the same period during two, usually consecutive, 16-hour days every week, centered on 1200 hours GMT, spanning both daylight and darkness in each Region. Calls of one to five whales of the same species distinguished on the same beam generally within a period of about four hours were considered one occurrence, and no new occurrence was logged for that day unless it was obvious that another set of calls had begun from a markedly different distance (sharp difference in level

and acoustic pattern). One dominant beam displaying the calls was identified for each occurrence. During analysis, a convenient interval for examining the data has been about four hours, and so often this period has been used as a practical minimum interval between new call occurrences. Call sequences often continued over much of the day, and therefore, were recorded as one occurrence. If similar call sequences were present on the same array beam on the second day, they were recorded as another occurrence. When there were too many whales (six or more, usually many more) of apparently the same species to separate, this concentrated calling noise which normally lasted for most of the day was recorded as one "J" occurrence (such noise was traditionally called "Jezz" by Navy analysts). When call sequences with acoustic patterns and spectra identifiable to specific call patterns of blue, fin, and humpback whales were noted, these were logged as a single call occurrence for each species. Background calling from other whales of the same species was not recorded so as to confine identification of calls to the most easily defined, closer calling.

Thus, the number of occurrences of whale calling did not provide a count of calling individuals or of the number of calls. Instead, they indicated the number of new call sequences within a period of about four hours or longer from

each species. These were identified on any of 40 beams for each of the different arrays in the four Regions of interest during the two 16-hour per day sampling periods. These data provided comparative measures of calling by each species and of the variations in calling with season and location.

Supplemented by data from a variety of other fixed and mobile hydrophone systems, locations for calling whales also could be assessed. To accomplish this, the same call had to be verified with detailed spectrograms of call sequences superimposed on two or more arrays. Triangulation from the directions for sound reception from the different hydrophone systems provided estimates of sound source positions. Multiple positions for successive call sequences from individual whales allowed refinement of their locations and tracking of their movements. The location of areas with concentrated calling apparently from numbers of whales also could be observed to change over time as local groups of calling whales moved, over days or weeks.

WHALE CALLS

Whale calls in these acoustic displays that were most recognizable with little confusion from other sounds had prominent low frequencies (propagating well) and were repetitive with tonal characteristics (distinguishable from ambient noise). Less repetitive and transient sounds readily masked by noise were not a part of these observations. The whale calling data analyzed here included species identification, occurrence of calling, and received beam without consideration of array orientation.

Call sequences from blue whales (Balaenoptera musculus) and fin whales (Balaenoptera physalus), and songs from humpback whales (Megaptera novaeangliae) were clearly identified on spectrographic displays of the beam-formed acoustic data from the hydrophone arrays. The occurrence of calls from each species was different in the four regions, varying with season and changing patterns of calling. Call occurrence for the different species generally was consistent between years, with similar patterns of calling recorded from similar directions (comparable array beams) during corresponding seasons.

The blue whale call sequences that were identified were their long series of repetitive, downswept tonal calls with

fundamental frequencies usually below 20 Hz and several harmonics, repeated variably at 3 to 10 min intervals, often over several hours. Shorter calls from this species were not consistently separable from noise and so were not a part of these analyses.

The fin whale call sequences that were identified were the repetitive, down-swept "20 Hz" pulse series with most energy near 20 Hz and little harmonic energy. Pulses of about 1 sec each were repeated regularly at rates of a few seconds in characteristic temporal patterns with three or four rests of a few minutes each hour over periods of 16 hours or more. The short sequences and social calls were not as easily separated from noise and so were not a part of these analyses. Fin whale calling analyzed here included call sequences that could be reliably distinguished as coming from individuals (labeled "F") and overlapping concentrations of calls from too many whales in a local area to allow separation (labeled "J"). The J component swamped concurrent calling by individuals, unless they were relatively close to arrays. Combining F and J components provided a more realistic measure of fin whale calling.

Humpback whale song components could be recognized reliably, although only the lower frequencies below a few hundred Hertz were typically received from distant whales.

NUMBERS OF WHALES CALLING

Judgements of the numbers of calling whales represented in these Whidbey data have been based on the experience of the observations to date. A relatively large amount of data and considerable familiarity with the spectral representations of the whale sounds were needed before realistic estimates of numbers of calling whales could be assessed. Doubtless such estimates will be refined as monitoring techniques develop over time and as the amount of data increase.

The estimated counts of calling whales (see page 140) were from assessments of the numbers of overlapping call sequences from different individual whales represented in the data for each calling event. The estimated numbers of calling whales were different on average for each species and varied with each season. They indicated seasonal differences in the numbers of calling whales of each species in each Region. They also were likely to be indicative of differences in whale behaviors with season and locality in the deep waters of the North Pacific. These estimates of numbers of calling whales were considered a beginning step toward quantification of the call data from these pelagic populations, representing the usual patterns of calling individuals noted in these observations of groups of whales.

Reviewing the call data from the arrays in detail allowed an indication of the usual numbers of whales that were involved in the call occurrences that were logged. The assessments were related to the general whale calling seasons. These were offset from the calendar year by one month to match the apparent cycle of whale calling -- Spring (March - May), Summer (June - August), Fall (September - November), and Winter (December - February).

Blue whale calling during their Fall peak season usually was from three to eight or more whales -- the average appeared to be from about five whales for each calling event, often from too many whales to separate. During the Winter as blue whale calling waned, and then during the Summer as it increased again, calling was from one to three whales so we have used 1.5 as the multiplier. During the Spring lowest calling season, only one whale usually was evident during each calling event.

Fin whale calling ("F" calls, distinguishable from individuals) during the peak Winter season was from one to five whales, averaging three calling fin whales per event. During the adjacent Spring and Fall seasons, calling was from one to three whales so a multiplier of 1.5 has been used.

During the Summer period of lowest fin whale calling, only one whale was evident during most calling events. The "J" calls by fin whales, however, regardless of season, were judged to be from six to very many more fin whales, so a multiplier of 6 has been used for all J calling. Combining the F and J calls likely provided a better assessment of the actual numbers of calling fin whales.

Humpback whale songs were evident usually from groups of whales, estimated at three or more individuals, singing during each event, regardless of location or season.

In addition to the individual whales of each species that were calling, of course, there were likely to be many more whales associated with them. Little is known of the numbers of calling individuals within groups of whales, and most such observations have been of inshore populations which may have quite different patterns of activity from the offshore whales. There has been little reliable information about the whales in offshore waters. These acoustic data represent some of the first consistent information that has ever been obtained for the deep-sea whale populations.

THE DATA

The whale call data have been collected in two forms: (1) occurrence of calls, and (2) location of call sources.

Occurrence of Calls -- The call occurrence data (see page 26) provided comparisons of the presence of calls on the different arrays from the different species. Calling was identified for the same time period relative to its presence on each of 40 beams on every array that was monitored. The regular sampling of these data year round over three to four years has allowed assessments of the distribution of calling whales and their seasonal occurrence.

Calls from blue whales (Balaenoptera musculus), fin whales (Balaenoptera physalus), and humpback whales (Megaptera novaeangliae) were clearly identified in spectrographic displays of the beam-formed acoustic data from the hydrophone arrays. The occurrence of whale calls from each species was different in the four Regions, varying with season and changing patterns of calling. Call occurrence generally was consistent between years, often with similar patterns of calling recorded from the same array beams during the same periods of different year. The call occurrence data for blue whales, fin whales and humpback whales from November 1995 through July 1999 have been plotted, beginning on page 26. These graphs compare the call occurrence data by

array and beam for each of the four Regions. The data for each year are compared for the different species.

Note that data for the NW and NC Regions were not available during November 1996 and October 1998.

Locations for Calling whales -- The location of calling whales provided good information on whales whose sounds were sufficiently separated from competing noise to be received well enough to be positively recognized on more than one array. Therefore, call locations could be achieved most when there were few calling whales of that species in the local area, and during periods of peak calling few calls could be separated sufficiently for source localization. Call locations showed the presence of considerable numbers of individual calling whales in all Regions and in all seasons. They also indicated movements of individuals when their calls were sufficiently unique for positive recognitions of sequential sounds. Therefore, the data on call locations were more variable over time and had different periods of peak abundance from the data on call occurrence.

Locations for calling blue whales within the four Regions were plotted relative to the month and season. Consistently, there were few fin whale call locations so these were plots were omitted. The locations for singing humpback whales were plotted by month for the SE Region only to show their strong

seasonal occupation of that area. No songs were heard in August, September and October (see page 146). Comparison of the call location data with the call occurrence data provided the best information on the presence of calling whales in the different Regions.

Track of 52-Hz Whale -- the track of a whale with unique 52-Hz calls is plotted for the 1998-1999 season (see page 156). This sound source has been the only one with this call structure in the entire listening area. We have been tracking this call since 1992, and have not identified the whale species -- perhaps it is a hybrid. The 52-Hz whale has consistently had movements that were somewhat similar to the migrations of many of the blue whales, but the timing of its presence in the area has been more like that of fin whales. The call patterns, however, have not been particularly like either blue or fin whales, although sideband frequencies (harmonic intervals) were compatible with many blue whale calls. The calls have dominant energies near 52-Hz and two or three side bands at intervals of approximately 17.5 Hz, but never any energy at a fundamental frequency. The pattern of call repetition and duration of individual calls as well as the sequence of calls has been highly variable, although the clustering of calls has been characteristic. The clustered calls, their frequency and sideband structure have allowed easy identification.

WHAT HAVE WE LEARNED?

Before these analyses of acoustic data, our knowledge about the presence of whales in the deep waters of the North Pacific was based only on occasional sightings.

Most of the previous whale data were from sightings during summer, usually daylight experiments and surveys. Acoustics had seldom been used for assessments of the presence of whales in these deep waters, although years of ship recordings had identified characteristic sounds from the different species. Few blue whales were thought to exist away from shelf waters where some were seen occasionally feeding, and these were considered likely to migrate to southern waters during winter. It was thought that there were not many fin whales in deep water, and they, too, were considered to migrate to southerly waters in winter. Humpbacks feeding in near-shore waters of Alaska were thought to move to calving areas, such as Hawaii, and usually to begin to sing when they reached those waters.

The data from SOSUS and other acoustic systems immediately corrected many of these ideas.

The new information was a surprise:

-- Whales heard by these systems were calling night and day in all the deep-water Regions and in all seasons.

-- Calling whales could be located and tracked over relatively long distances (without any whale disturbance).

-- Calling whales of the each species were distributed differently in each season, and call patterns within species could be correlated with shifting components of the populations. The ocean-wide monitoring provided a truly comprehensive view of whale call distributions.

-- Blue whales calls were found to be numerous over all the deep-water North Pacific Regions, especially and surprisingly in the NW Region. Blue whale calling peaked in autumn, but continued at reduced amounts in most areas during all seasons.

-- Many blue whales did not migrate, but they remained in the different Regions and continued to call throughout the year.

-- Fin whales calls were concentrated in localized deep water Regions at all latitudes in relatively large numbers during winter, and there were few calls in summer.

-- Fin whales did not have any noticeable migratory movement to the south in winter.

-- Humpback songs began seasonally in the deep waters of the NC Region, then moved to the middle and southern areas of the SE, skipping the intervening waters. Songs normally continued in the southern part of the SE Region throughout the winter.

-- Singing humpbacks in the SE Region mostly moved southward in December and January, northward in April/May, and they moved both to the south and the north during February and March.

-- During the unusual El Niño/La Niña conditions of the 1998/1999 season, there were no singing humpbacks in the SE Region.

-- The data on the occurrence of calling whales in the deep waters of these North Pacific Regions have allowed predictive assessments of their locations, seasonality, and movements. In addition, judgements can be made of potential effects of environmental perturbations (El Niño/La Niña) on whale calling in different Regions.

-- The reliability of such assessments and predictions has continued to increase with each additional set of data added to the call databases.