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Baleen whale acoustic activity in the North Pacific: historical analysis and current occurrence

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NAVAL POSTGRADUATE SCHOOL

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Baleen Whale Acoustic Activity in the North Pacific: historical analysis and current occurrence

by

Kathleen M. Stafford

December 2007

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13. ABSTRACT *(maximum 200 words)*

Unclassified historic acoustic data were used to examine long time scale changes in the seasonal and geographic occurrence of large whales in the Pacific and to correlate these changes with oceanographic variables such as sea surface temperature, chlorophyll *a*, etc. Distribution of northeastern Pacific blue whales (as indicated by the numbers of their calls), while insignificantly related to SST, did show a clear seasonal pattern both to chl *a* concentration (negative) and to the mixed layer depth (positive). It was speculated that the negative correlation with chl *a* might be due to a lag from primary to secondary productivity: as phytoplankton are eaten by zooplankton (which in turn become available to whales), the overall amount of chl *a* decreases.

It is recommended that in collaboration with other agencies hydrophones be deployed in the northeastern Gulf of Alaska to provide current information on the occurrence of vocally active whale species, including low-frequency baleen whales and higher frequency odontocetes. A likely time might be during the Northern Edge 2008 exercise in Prince William Sound. Meanwhile, a new efficient, low-power, low-cost recorder that can be easily deployed, in an array with other instruments or independently, from a mid-size vessel is being developed.

14. SUBJECT TERMS Blue whale (*Balaenoptera musculus*), blue whale acoustic activity, blue whale detection, blue whale acoustic monitoring, blue whale distribution/concentration, eastern tropical Pacific, North Pacific, Gulf of Alaska, Prince William Sound

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Baleen Whale Acoustic Activity in the North Pacific: historical analysis and current occurrence

Final Report

Submitted pursuant to award number N00024-02-D-6602

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Project Overview

This project was divided into two tasks: the first of these was a study of archived historical acoustic data from the North Pacific Ocean and the second was a feasibility study of the collection of current acoustic data from the North Pacific. The first task was to use historic data to examine long time scale changes in the seasonal and geographic occurrence of large whales in the Pacific Ocean and correlate these with oceanographic variables such as sea surface temperature, chlorophyll *a* and sea surface height. The second task was to investigate and recommend deployments in collaboration with other agencies to deploy hydrophones in the northeastern Gulf of Alaska to provide information on the occurrence of vocally active whale species, including low-frequency baleen whales and higher frequency odontocetes. In more detail, the tasks and their milestones were as follows:

Task 1:

Use recently developed automatic detection techniques for blue and fin whale calls and apply these to a subset of data from the 7-year time series of acoustic data archived at NOAA's **P**acific **M**arine **E**nvironmental **L**aboratory in Newport OR. These data include PMEL-moored hydrophone data (unclassified) from the eastern tropical Pacific and the Gulf of Alaska.

a) Annual, seasonal and geographic variability of blue and fin whales in the Pacific from unclassified data sources
    a. Milestone: Paper to appear in the Journal of the Acoustical Society of America in December 2007 on the occurrence of blue, fin and humpback whales in the Gulf of Alaska (Stafford, K.M., D.K. Mellinger, S.E. Moore, and C.G. Fox, 2007. Seasonal variability and detection range modeling of baleen whale calls in the Gulf of Alaska, 1999-2002. *Journal of the Acoustical Society of America* **122**: 3378-3390). (Appendix I).

    b. Milestone: Report on the long-term occurrence of blue whales in the eastern tropical Pacific. (Appendix II).

b) Assessment of the best tools for automatic detection of calls
    a. Milestone: Spectrogram correlation appears to work best for blue whale call detection from the eastern tropical Pacific, while examination of spectra for 15-35 Hz from which the median values have been removed appears to be most efficient for SOSUS data.

c) Predictive model for baleen whale occurrence in the context of oceanographic variables and detection distances
    a. Milestone: Presentation at the 4th joint meeting of the Acoustical Societies of America and Japan. (Abstract presented in Appendix II).

b. Milestone: Paper to appear in the Journal of the Acoustical Society of America in December 2007 on the occurrence and detection distances of blue, fin and humpback whales in the Gulf of Alaska. Abstract attached as Appendix I.

c. Milestone: Poster for the University of Washington Space Undergraduate Research Program presented by undergraduate student Jessica Warner: "Evaluating the long-term trends of blue and fin whales using acoustic data in the northern Pacific Ocean."

Task 2:

Determine the feasibility of deploying acoustic data recorders in the Gulf of Alaska in conjunction with other organizations (i.e., National Data Buoy Center, Pacific Marine Environmental Laboratory, and University of Alaska). This will involve contacting people and organizations that might provide low/no-cost platforms in the Gulf of Alaska for the deployment of 3 hydrophones. Areas to investigate include regions that may be affected by Naval Northern Edge exercises.

The long-term goal of this task is to provide new acoustic data from areas previously unsampled in which cetaceans are known to occur and where Navy Northern Edge range exercises may be undertaken.

a) Establish instrument availability and partnerships; *and*
b) Survey of extant moorings; determine possible locations, platforms and feasibility of time frame for instrument deployments.

Milestones:

Our initial plan was to deploy during an August 2007 field season Passive Acoustic Listening (PAL) devices in Prince William Sound (PWS) on moorings planned by the Alaska Ocean Observing System (AOOS). To this end, conversations with Dr. Carl Schoch (formerly of AOOS) were held, and Dr. Jeff Nystuen and I wrote a project description (Appendix I) for this joint experiment. Instruments would be deployed in PWS on extant moorings managed by the National Data Buoy Center. During planning stages, meetings were held with Dr. Schoch and Jennifer Ewald of NOAA COOPs program. Dr. Nystuen attended an October 2006 meeting (*A Demonstration of the Alaska Ocean Observing System in Prince William Sound*) in Seattle to discuss existing infrastructure (Appendix IV). Unfortunately, the joint experiment fell through due to lack of funding for the collaboration and deployment/recovery of instruments.

Because this opportunity fell through and we realized that we needed to record time series data, not just the spectra recorded by PALs, and due to the lack of available instrumentation for this purpose, the funds for instrument lease were re-programmed with matching funds from the Applied Physics Laboratory towards the development of such an instrument.

There are few off-the-shelf instruments for recording long term sound in the ocean that are capable of flexible sampling schemes (both in terms of sample rate and duty cycle) and can last for up to 12 months in the ocean. Most of the underwater acoustic recorders to date were designed for geophysical experiments with fixed, low-frequency sample rates. Cetaceans (whales and dolphins) produce vocalizations in the widest range of any Order in the animal kingdom – from sub- to super-sonic. Baleen whales tend to vocalize between 10-5000 Hz, while odontocetes (toothed whales) vocalize from a few to 100's of kHz. Because different field experiments target different species in different oceans, we need a single instrument that is flexible enough that the software (rather than the hardware) can be modified to fit the needs of different studies. For instance, a study monitoring only blue and fin whales would be best served by a low sample rate (because these animals vocalize at very low frequencies (<50 Hz)) and high duty cycle to record entire vocalization bouts. A study in an area with many species would require a larger bandwidth (higher sample rate) but a lower duty cycle to both reduce analysis time and conserve hard drive space and battery power. Now that hard drives are quite small, the main limitation to these instruments is battery life, which is limited for the most part by instrument size.

We are developing an efficient, low-power, low-cost recorder based on new embedded processing technology (Analog Devices Blackfin DSP) that can be deployed either in an array with other instruments or on its own, and that can easily be deployed from a mid-size vessel. The new hydrophone systems will be Ethernet capable and use low power USB mass storage devices (USB sticks and solid-state drives).

Figure A. A) Recorder external view. B) Front of the “guts” showing USB flash hard drive, which can be switched out easily as capacity increases. C) Back of the “guts” illustrating the small size of the processor.

c) Report to NPS with recommendation for hydrophone deployments and time frame
   a. Milestone: Once it was clear that our initial plan to work with AOOS in Prince William Sound was not going to happen in 2007, we opted to direct our efforts towards deploying instruments on stand-alone moorings in the Northern Edge operating range before, during and after the 2008 field exercise. Three instruments will be deployed within the range boundaries; two of these will sub-sample at high (96 kHz) odontocete-range frequencies and be placed on the shelf, while the third and fourth will sample at lower (5 kHz) baleen whale-range frequencies (Figure B). Assuming the operation dates remain in May 2008, the instruments will be deployed from mid-April to early June to cover the time periods of before, during and post exercise.

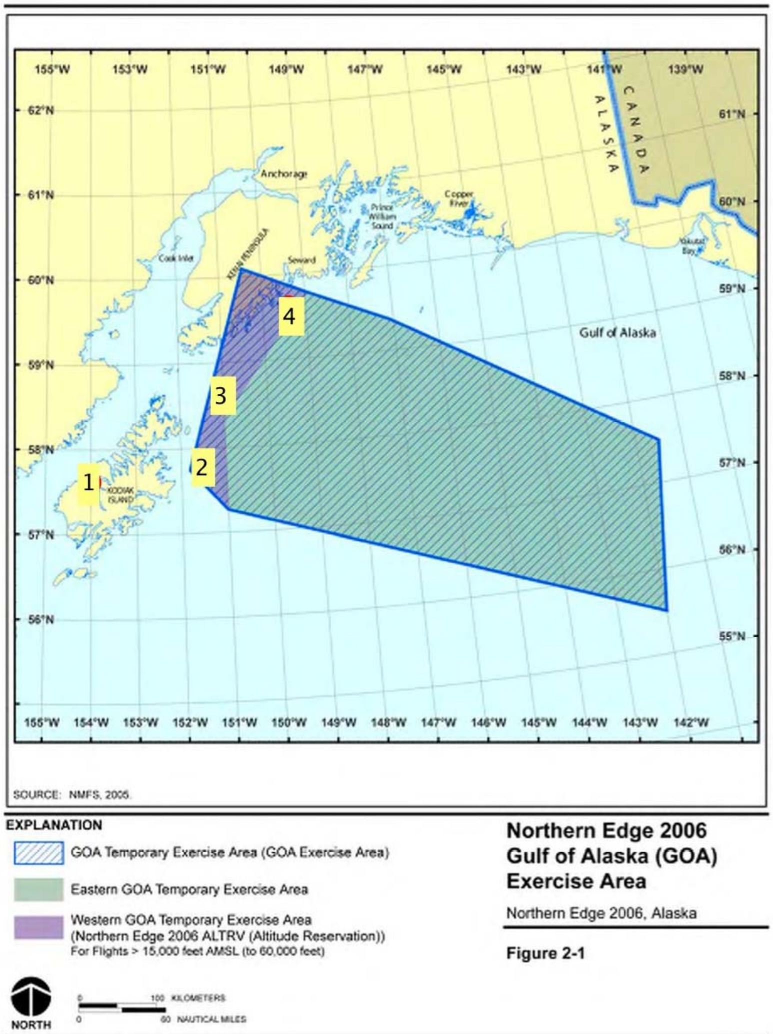

Figure B. Rough location of Northern Edge 2006 (and likely 2008) exercise area with proposed moored hydrophone locations shown as numbers. Instrument 1 will serve as a control well outside of the range.

Appendices for Final Report submitted pursuant to award number N00024-02-D-6602

<u>Appendix I.</u> Seasonal variability and detection range modeling of baleen whale calls in the Gulf of Alaska, 1999-2002. (*Abstract*)

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Five species of large whales, including the blue (*Balaenoptera musculus*), fin (*B. physalus*), sei (*B. borealis*), humpback (*Megaptera novaeangliae*), and North Pacific right (*Eubalaena japonica*), were the target of commercial harvests in the Gulf of Alaska (GoA) during the 19th through mid-20th Centuries. Since this time, there have been a few summer time visual surveys for these species, but no overview of year-round use of these waters by endangered whales primarily because standard visual survey data are difficult and costly. From October 1999-May 2002, moored hydrophones were deployed in six locations in the GoA to record whale calls. Reception of calls from fin, humpback, and blue whales and an unknown source, called Watkins' whale, showed seasonal and geographic variation. Calls were detected more often during the winter than during the summer, suggesting that animals inhabit the GoA year-round. To estimate the distance at which species-diagnostic calls could be heard, parabolic equation propagation loss models for frequencies characteristic of each of each call type were run. Maximum detection ranges in the subarctic North Pacific ranged from 45 to 250 km among three species (fin, humpback, blue), although modeled detection ranges varied greatly with input parameters and choice of ambient noise level.

(2007. *Journal of the Acoustical Society of America* **122(6)**: 3378-3390.)

<u>Appendix II.</u> Abstract of presentation from the 4th Joint meeting of the Acoustical Society of America and the Acoustical Society of Japan, November 2006.

Detection distances of the sounds of large whales recorded on hydrophones in the offshore Gulf of Alaska (A)

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The current status of most species of endangered baleen whales, including blue, fin, and humpback whales, in the Gulf of Alaska is unknown due to a lack of basic information on distribution and seasonal abundance. Remote passive acoustic monitoring can provide this information for vocal whales. However, to begin to estimate an index of abundance of calling animals, the distance at which they can be detected needs to be determined. In order to estimate transmission loss, a parabolic equation acoustic propagation model was used to provide mean loss estimates along four transects at 0.1a intervals to 5a to the N, E, S, and W from each of four receivers moored in the sound channel for species-specific frequencies and at depths at which the animals are thought to produce sound. For all species and locations, the detection range was largely determined by the choice of ambient noise levels. This suggests that masking due to anthropogenic noise could limit the range over which these animals can be detected by the moored instrument and, more importantly, the range over which they might communicate.

<u>Appendix III:</u> Blue Whale Acoustic Detections and Environmental Conditions in the Northern Eastern Tropical Pacific

Introduction

Blue whale calls worldwide are characterized by long durations (>20 s) and low fundamental frequencies (<30 Hz). Despite these similarities, blue whale calls show stable geographic variation. The most common vocalization produced by blue whales belonging to the "northeastern Pacific" population (Caretta *et al.* 2004) is a two part call consisting of an amplitude modulated 16s call at ~16 Hz (commonly referred to as "part A") followed 30 s later by an 18-s long, frequency modulated call that sweeps from about 18 to 16 Hz ("part B," Thompson *et al.* 1996). These calls are often produced in long, repeated sequences (Stafford *et al.* 1999a). This call type is recorded coastally from the Gulf of Alaska south to the equator (Stafford *et al.* 1999b; Stafford 2003).

The eastern tropical Pacific (ETP) has been thought to be a wintering ground for northeastern Pacific blue whales (Berzin 1978; Wade and Friedrichsen 1979), although blue whales are found in the ETP year-round (Reilly and Thayer 1990). Because the ETP is a region of year-round high productivity, blue whales likely forage in this region (Wade and Friedrichsen 1979; Reilly and Thayer 1990; Palacios 1999; Fiedler 2002). Recordings over the period of one year, from May 1996-May 1997 at 8° N 95° W, showed that eastern North Pacific type calls were most frequent from November through May and that these sounds were the most common large whale vocalization for this location (Stafford *et al.* 1999b).

Beginning in May 1996, NOAA's Pacific Marine Environmental Laboratory moored an array of six autonomous hydrophones to the east and west of the East Pacific Rise in order to monitor underwater earthquake and volcanic seismicity in the region. Upon examination of the data, it became immediately apparent that a large contributor to the regional ambient noise was the low-frequency calls of large whales. The instruments consist of an anchor, an acoustic release, an ITC 1032 hydrophone (flat response from 1 Hz to 32 kHz and sensitivity of -192 dB re 1V/μPa; preamplifier sensitivity of -130 dB re 1V/μPa) and recorder in a pressure-resistant titanium case, and flotation. The instruments are moored near the sound channel axis at depths of 650-750 m below the surface. The packages were initially designed to record for up to six months at a sampling rate of 100 Hz with low-pass filters set at 40 Hz. Deployments after November 1999 archive data for 1-2 years at sample rates of 250 Hz (low-pass at 110 Hz). The data are archived on board the mooring until the instrument is recovered. The data are then downloaded and the instrument redeployed.

This array has provided the longest, nearly continuous, unclassified record of whale calling to date (~6.6 yr). Although other studies using similar data sets have described the seasonal patterns, in this paper we take advantage of the length of the record to focus on the interannual signal in relation to recent environmental changes in the eastern tropical Pacific.

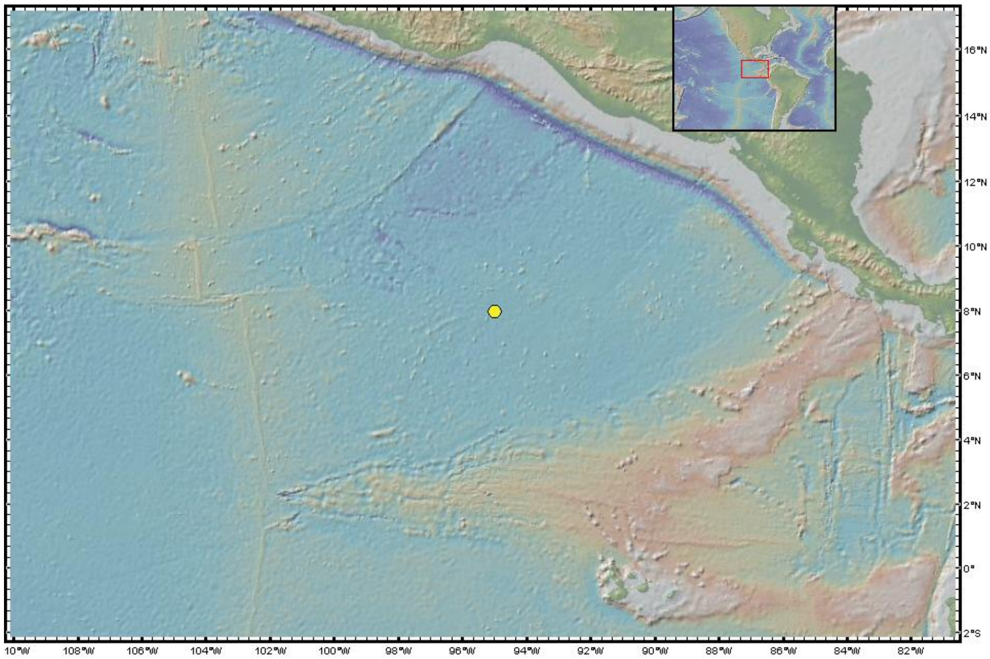

Figure 1. Map of eastern tropical Pacific showing location of the hydrophone whose recordings were used for blue whale call detection. Hydrophone is shown as a yellow circle.

Data and Analysis

The entire acoustic data set for 8°N 95°W (May 1996-December 2002) was scanned for blue whale B calls using the automatic detection method of spectrogram correlation (Mellinger and Clark 2000). Only data on B call occurrence were used because B calls are the most reliably detected blue whale sound. This involved specifying frequency contours and durations that matched average characteristics of these calls. For this study, a simple downsweep from 17.8 Hz to 16 Hz over 18 s was used as a detection kernel. Additionally, spectrogram noise equalization with a time constant of 40 s was employed to eliminate continuous interfering tones such as those from ships. The detection threshold was set fairly high in order to reduce the number of false detections. Therefore, number of calls detected should be considered a minimum value. Detections were saved as individual sound files that were assessed visually to distinguish correct and incorrect detections. These automated results were compared to data that had been visually verified for 1996-1997 (Stafford *et al.* 1999b). The total number of calls by month was plotted to examine seasonal patterns in call detection.

To examine whether interannual changes in sea surface temperature might have contributed to interannual changes in call detection, data from conductivity-temperature-depth (CTD) casts taken in February at 8° N 95° W during NOAA's Tropical Atmosphere and Oceans (TAO) cruises were obtained to determine sound velocity profiles (SVP) for comparison with mean SVPs obtained from the Generalized Digital Environmental Model (GDEM, Version 2.6, Naval Oceanographic Office, https://128.160.23.42/gdemv/gdemv.html). February was chosen for comparison because the February 1998 SVP best reflected the El Niño induced surface warming. Four TAO

CTD casts (including one from mid-January) were available and compared to the mean GDEM SVP.

Satellite data for chlorophyll *a* (chl *a*) concentration and mixed layer depth (MLD) were obtained from SeaWIFS (http://oceancolor.gsfc.nasa.gov/). Sea surface temperature (SST) and height were obtained from the Physical Oceanography Distributed Active Archive Data Center at the NASA Jet Propulsion Laboratory, Pasadena, CA (http://podaac.jpl.nasa.gov). These data were downloaded as area-averaged time series for the northern ETP.

Monthly time series for the four variables (call counts, chl *a*, SST, MLD) were compared from September 1997-December 2002, as these were dates when data from all variables were available.

Since one of the goals of this project was to build a model to predict one variable (call counts) given values of chl *a*, SST and MLD, we used multiple regression of the 3 latter on the dependent variable of call count.

Results

Northeastern Pacific blue whales were recorded seasonally in the ETP, with calls recorded most often February through August (Figure 2). Fewest calls were recorded during the 1997-98 El Niño, which was not unexpected; but few calls were also recorded in 2001-2002, which was surprising.

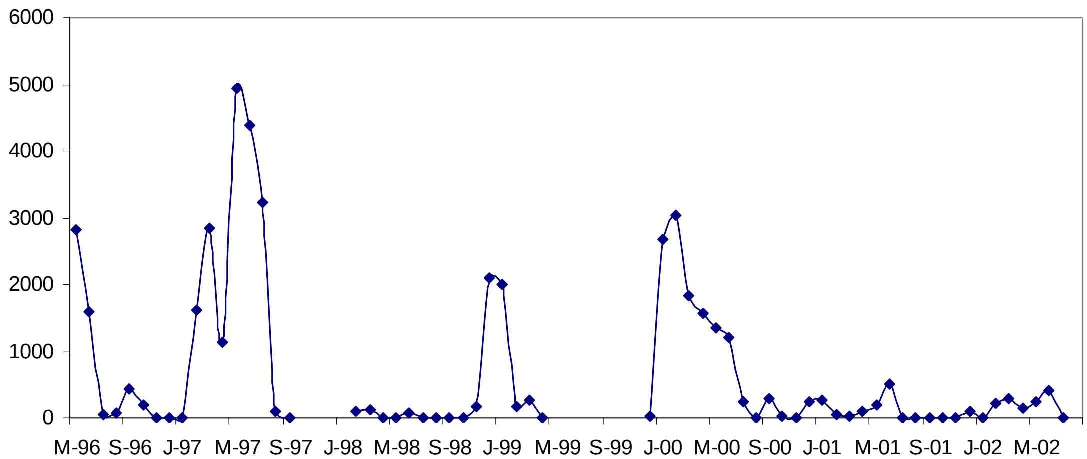

Figure 2. Number of blue whale "B" calls detected by year at 8°N 95°W from May 1996-October 2002. Data were unavailable from October 1997-February 1998 and from June 1999-December 1999.

Four TAO CTD casts (including one from mid-January) were available and compared to the mean GDEM SVP (Figure 3). A parabolic equation model (Collins 1993, 1995) was used to compare the transmission loss for a 16 Hz source at 20 m received by a hydrophone at 850 m. In general, the difference in transmission loss among the different SVPs was less than 2 dB (Figure 4).

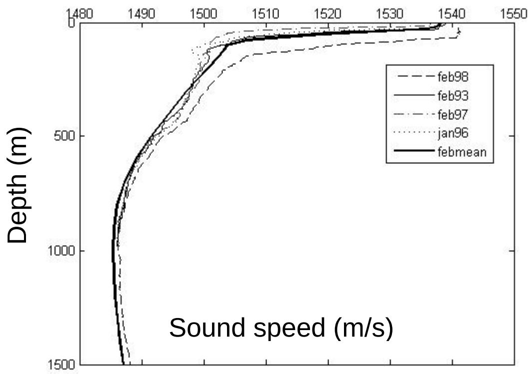

Figure 3. Sound speed profiles for February from TAO CTD casts and mean GDEM values.

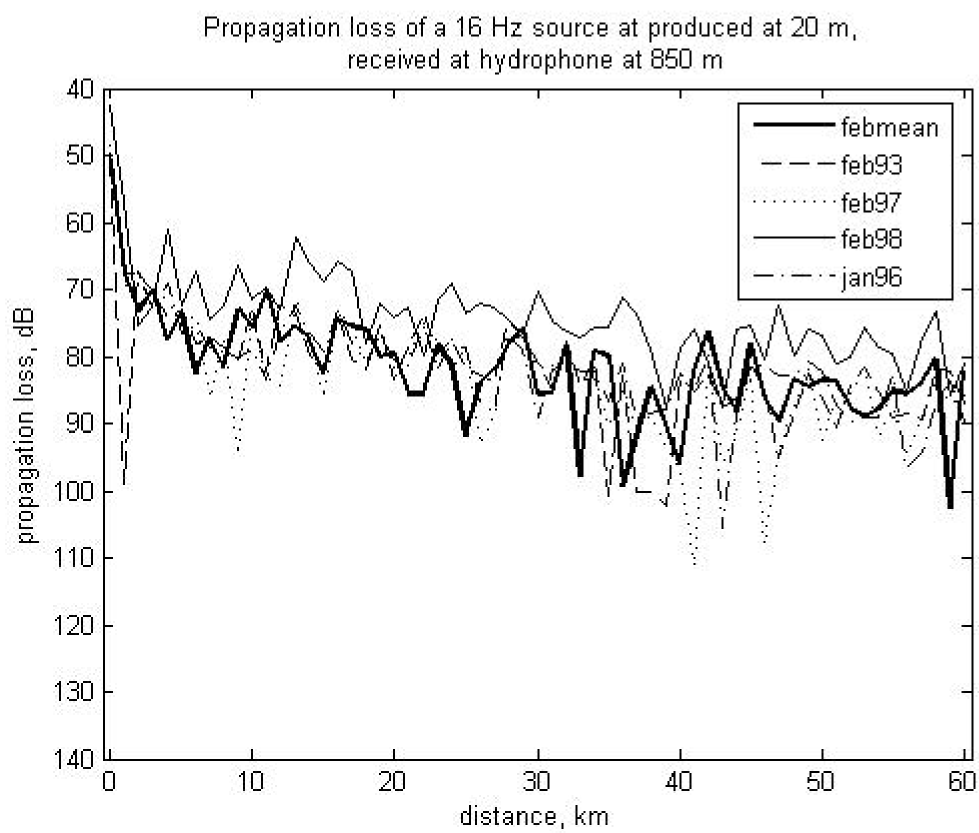

Figure 4. Transmission loss values for a blue whale B call (16 Hz) from 4 different years based on the sound speed profiles from Figure 3. Note that transmission loss is lowest during the El Niño year (solid thin black line), which rules out reduced call reception in this year as a reason for the very few call detections.

During this same time frame, chlorophyll *a* concentration also showed seasonal patterns (Figures 5 and 6). Figure 5 shows maps of chl *a* in the study area divided into the three periods that seem to be represented in the blue whale call data: 1997-1998 El Niño (Figure 5a), where there was very little chl *a* in the whole of the ETP; end 1998-mid 2000 (Figure 5b), where both chl *a* and blue whale calls were abundant; and mid-2000-

end 2002 (Figure 5c), where chl *a* was abundant but blue whale calls were not. Plotting the chl *a* time series shows the data above, but also shows an overall increasing trend in chl *a* after the very low numbers from the El Niño year (Figure 6).

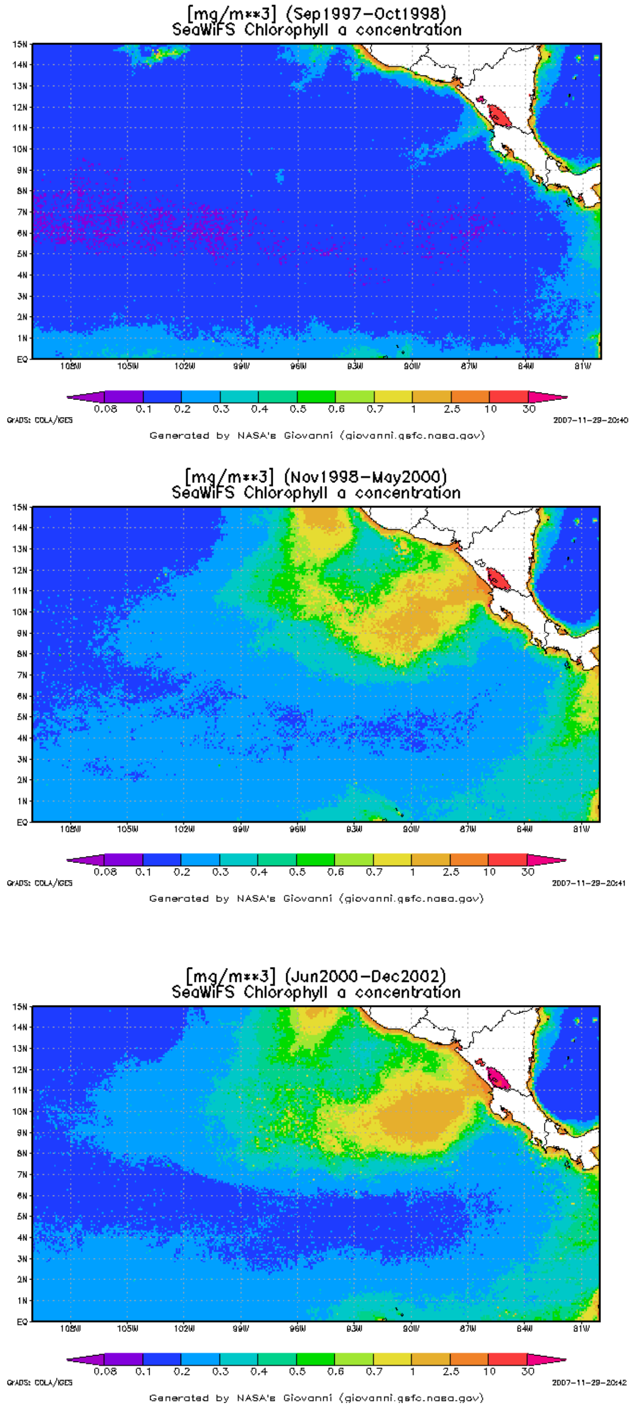

Figure 5. Chlorophyll *a* concentration from SeaWIFS for a) September 1997-October 1998, b) November 1998-May 2000 and c) June 2000-October 2002. These plots show little chlorophyll during the 1997-98 El Niño and extensive chlorophyll in later years.

The images and data used in this study were acquired using the GES-DISC Interactive Online Visualization ANd aNalysis Infrastructure (Giovanni) as part of the NASA's Goddard Earth Sciences (GES) Data and Information Services Center (DISC).

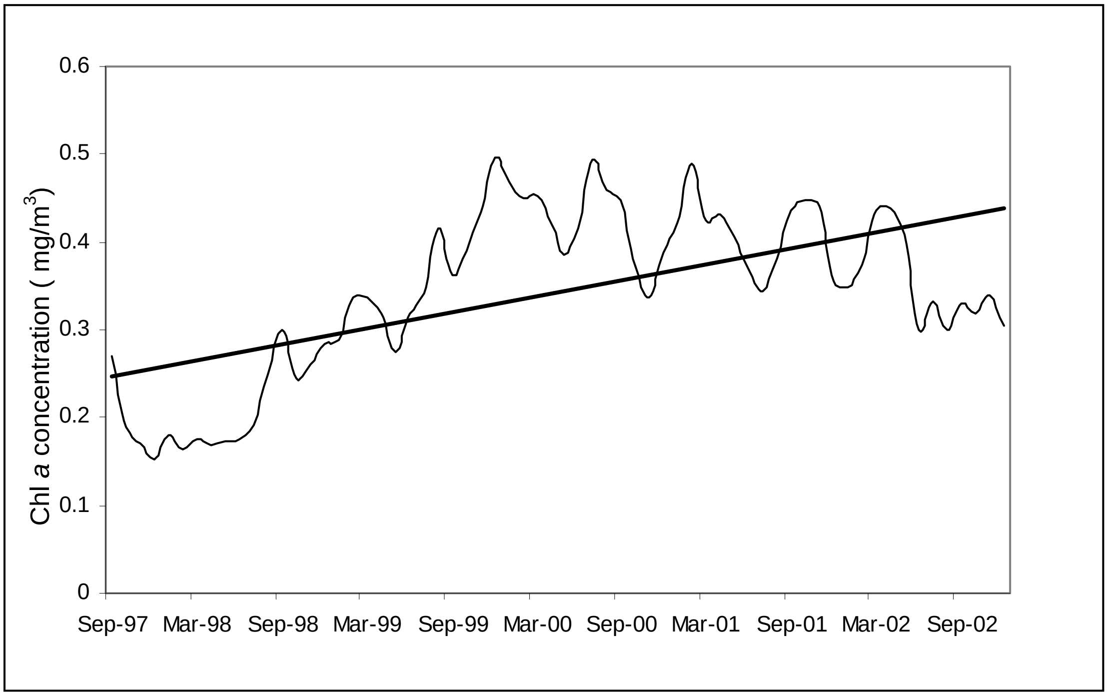

Figure 6. Time series of chlorophyll *a* data from SeaWIFS showing low levels during 1997-1998 and an overall increase in the broad study area from 1997-2002. Data were only available starting in September 1997.

Sea surface anomaly temperature data for the time series show evidence of much warmer surface waters during the El Niño year, which is an indication that little upwelling, hence primary productivity, was occurring during this time. Post-1998, the region returns to a more normal seasonal pattern, with highest temperatures during the fall and winter and lowest during the spring and summer, which is when blue whale call numbers are greatest (Figure 7).

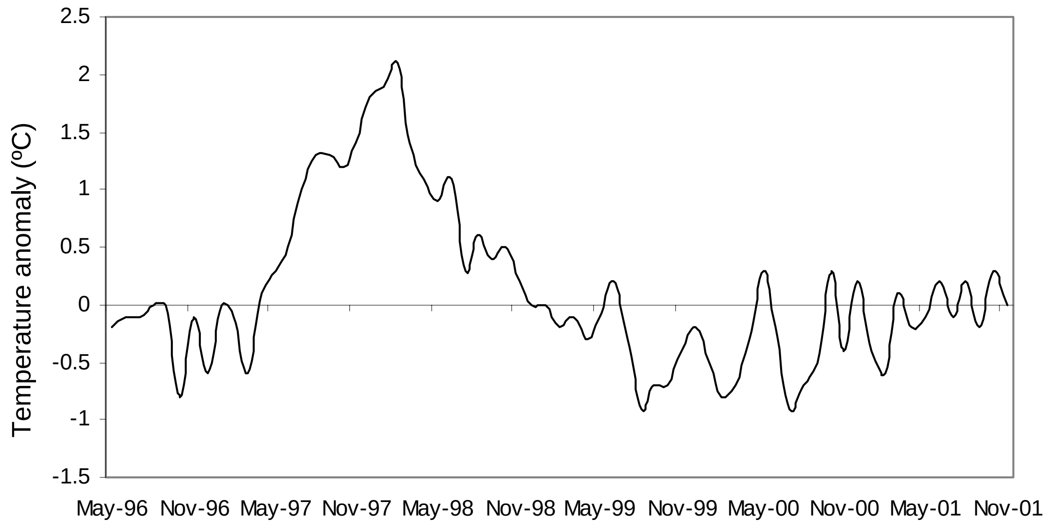

Figure 7. Sea surface temperature anomaly data (time series minus the long term mean) for the eastern tropical Pacific. Note that the El Niño year shows values well above the expected mean for almost 18 months.

As with all other variables, the MLD shows less mixing during the El Niño year than later in the time series. Post- El Niño years show clear patterns of wind-driven mixing during the fall and winter, with relaxation during the spring and summer (Figure 8).

Outside of El Niño years, then, all the oceanographic data point to increased mixing, decreased SSTs and increased productivity during the months just prior to those in which blue whale calls are most abundant.

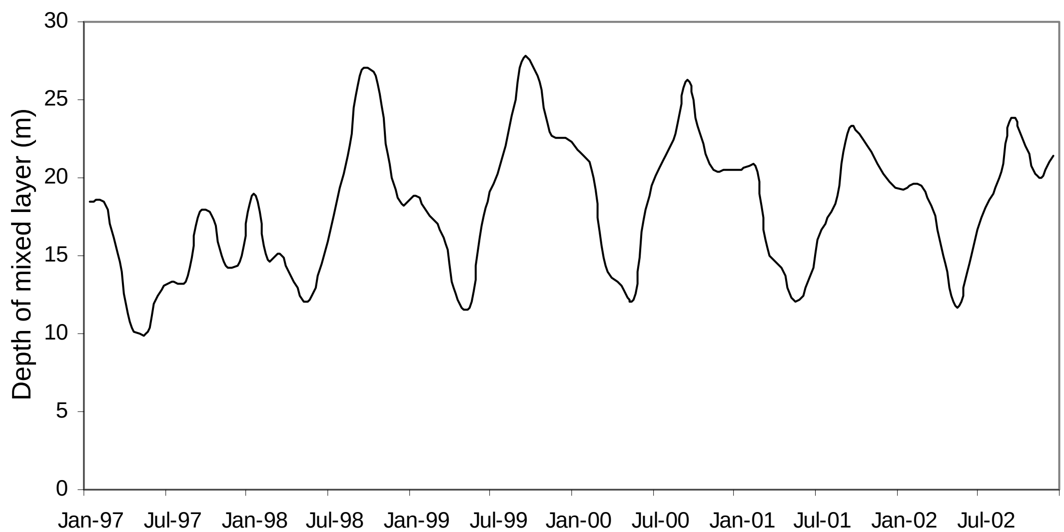

Figure 8. Mixed layer depth for the northern eastern tropical Pacific.

The initial result of multiple regression analyses suggested that SST was not a significant variable in predicting call count. So it was removed from the model. Further, the distribution of call count was not normal, and therefore the variable was log transformed. Subsequently, the new regression produced a statistically significant model (p value = 0.002) that accounted for 22-26% of the variability in log(call count). The R^2 value when adjusted for the degrees of freedom is 22.3% versus the unadjusted value of 26%. The resultant model equation is:

$$\log(\text{count}) = 4.85429 - 11.3282 * \text{chl} + 0.239438 * \text{MLD},$$

where both chl *a* and MLD values are statistically significant at p-values less than 0.05. Therefore, it appears that chl *a* **AND** MLD are important predictors of whale call occurrence in the ETP. Because chl *a* had a negative value, we introduced lags of 1-3 months in call count. The best fit (R^2 = 28.8%, p-value = 0.001) of the lagged counts model came with a one-month lag, but the constants for chl *a* and MLD were not very different.

Discussion

While the calls of northeastern Pacific blue whales are recorded in all months of the year in the ETP, they show a clear seasonal pattern that can be related both to chl *a* concentration (negative) and to the depth of the mixed layer (positive). The negative correlation with chl *a* may be due to a lag from primary to secondary productivity: as phytoplankton are eaten down by zooplankton which then become available to whales, the overall amount of chl *a* decreases.

Blue whales are primarily Euphausiid (krill) predators. Krill have the highest biomasses of all zooplankton grazers in the eastern tropical Pacific (Brinton 1962; Longhurst 1976; Fiedler 2002). The rapid response by the blue whales to environmental changes can be explained in terms of the simple and direct trophic system they exploit. In upwelling systems it is a very short food (3-step) chain: phytoplankton→ euphausiids→ whales (e.g., Mangel *et al.* 2002). Thus, when environmental conditions change on annual and interannual time scales, the effects are felt rapidly. It is evident that blue whales are finely tuned to these variations. In both the North Pacific and the Antarctic, the presence of blue whales was correlated with the presence/absence of euphausiid prey species (Berzin and Rovnin 1966). The Japanese described "Calanus years," when copepods were most abundant, and contrasted these to "krill years," when euphausiids and blue whales were abundant (Nemoto 1955). In the Antarctic, whalers distinguished "blue whale years" from "fin whale years," and considered these differences to be due to the abundance of krill (Mackintosh *et al.* 1929; Ruud 1932; Hjort 1933).

Although there are few contemporary data on the abundance of krill in the ETP, we can compare other systems to help draw conclusions. For instance, there was a large reduction in zooplankton biomass in Monterey Bay in the summer and fall of 1997 (Marinovic *et al.* 2002). The dominant euphausiid species, *E. pacifica*, declined in abundance, as did *T. spinifera*. By contrast, numbers of the warm water euphausiid *N. simplex* increased and maintained high levels throughout the warm El Niño period and disappeared from samples almost entirely as SSTs cooled. Zooplankton abundance and distribution were impacted most obviously from August 1997 through April 1998. Increases in SST, deepening of the thermocline and the resultant decrease in primary productivity was hypothesized to have caused both the displacement northward and increased mortality of cool water species (Marinovic *et al.* 2002). At the same time, a significant relationship was found between maximum krill backscatter and the density of blue whales in Monterey Bay, California. Whales were most abundant when krill was most abundant. During the late summer/early autumn of 1997 (El Niño year), both krill and whale numbers decreased. Overall, productivity in Monterey Bay decreased, especially > 50 km from shore (Benson *et al.* 2002).

The data presented here suggest that change in blue whale calls may be a response to redistribution of the prey field, either through lack of calling (and/or potential absence) during the low-productivity El Niño year or by redistribution of the wintering blue whale population in response to the expansion of the productive habitat and therefore enhanced foraging opportunities. In the latter instance, it might be hypothesized that blue whales are present in the ETP from 2000 onwards, but are not as concentrated near the highly productive Costa Rica Dome (CRD), as productivity levels ETP-wide increased over time.

Because blue whales are big, mobile predators, they are able to adapt relatively quickly to broad-scale changes in the environment, which may buffer them somewhat from temporary changes in oceanographically driven prey availability. Although changes in SST are a harbinger of El Niño/La Niña events, wind driven changes in MLD and overall decreased productivity are the variables that appear to most influence blue whale calling behavior in the ETP. What remains unknown is whether decreased calling behavior indicates fewer blue whales in the region, as might be expected during an El Niño event. It might also indicate that animals are more spread out and less likely to be recorded by a single instrument. These are data that can only be obtained by continuing long-term acoustic monitoring of the ETP and by adding more recorders to the area.

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Appendix IV. Proposal for participation in the Prince William Sound field experiment

Acoustic Monitoring in Prince William Sound

Ancillary Project: Passive Acoustic Monitoring in PWS Field Experiment
PIs: Jeff Nystuen, Kate Stafford, Sue Moore

Goal: To characterize the ambient sound budget of PWS. (physical, biological and anthropogenic)

Scope of work: Deploy 2-3 Passive Aquatic Listeners (PALs) in PWS before and during the proposed 2007 field experiment.

Background: The ambient sound field contains quantifiable information about the marine environment. PALs can be used to quantify wind and rainfall (including light drizzle), detect and record whale calls, detect and quantify human activities (including large ships and smaller fishing and whale watching boats).

Needed AOOS resources: Moorings, preferably sub-surface, on which to mount the PALs. PALs are light and easily deployed on moorings.

Resources offered: PALs are available for deployments. There will be a small cost for refurbishment and shipping. Dedicated sub-surface moorings could be offered for $20K each.

Who will do the work?

1) Deployment should be with planned mooring efforts – Jennifer Ewald (NOAA) or AOOS (Claude – PWSSC) moorings.
2) Data analysis will be by the PIs (Nystuen, Stafford, Moore, or students, APL (2 months?)
3) Publications will be expected

When do you want to be in the field? Not necessary, but it would be nice to visit PWS to understand the likely underwater sound sources and inspect the structure of the moorings.

Relevance to the main goal of the exercise (oil spill response): The ambient sound field does contain information about the environment that may be useful for oil spill response, but this is really an ancillary project with high potential "discovery".

1) Is there a sound, or change in the sound field, that is associated with oil spills?
2) Since rainfall rate is quantified acoustically, the PAL data will provide a direct measure of fresh water input to the surface of PWS. The role of this source of fresh water on the circulation of PWS is unstudied and unknown. Furthermore, no traditional rain gauges can be deployed over the water.
3) Information about shipping is present in the sound record – when, where and how loud? The baseline sound budget for PWS has not been established. The

PAL recordings will provide this budget, and it should be useful for future decisions regarding the impact of human-generated noise on the underwater marine environment of PWS.

4) Finally, the sound bites recorded on the PALs are "fun" to listen to, and can and should be used as part of outreach and education activities associated with the experiment.

Funding: The principal cost will be for data analysis and presentation. This is 2-3 months of PI time and is roughly $30-50 K. NOAA Alaska Fisheries has an interest in using PALs to monitor the marine environment and may be a source for funding. Joe Banda at PWS-RCAC described a program that might be willing to sponsor this project.

Title of tentative publication: The Ambient Sound Budget of Prince William Sound – Rain, wind, whales and ships detected by listening. Potential collaborators: physical environment (Okkonen?); NGOS (Matkin, Saulitis) to identify KW ecotypes, Outreach activities (AOOS).

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