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Monitoring cetaceans in the North Pacific: analysis of retrospective SOSUS data and acoustic detection on the Northern Edge Range

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NAVAL POSTGRADUATE SCHOOL

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Monitoring cetaceans in the North Pacific: analysis of retrospective SOSUS data and acoustic detection on the Northern Edge Range

by

Kathleen Stafford

December 2010

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14. ABSTRACT
To comply with environmental laws, the U.S. Navy has increasingly relied on acoustic detection and tracking for marine mammal monitoring/mitigation. In the North Pacific, much of what is known about large whale seasonal occurrence comes from Sound Surveillance System (SOSUS) arrays. SOSUS provides broad basin-scale assessments of large whale seasonal occurrence, but cannot provide detail at the regional level, in particular here for the Navy's Northern Edge (Training) Range in the northern Gulf of Alaska. Here, data from long-term acoustic observations of basin-wide data, and from a short-term, nearshore acoustic deployment in the NER, are presented.

For the long-term observations, Navy-analyst derived detections of blue and fin whales were compared with spectral data to determine if there is a reliable way to separate the two species in the spectral data. Although the degree to which detections matched the spectra varied with frequency range, generally blue and fin whale detections matched the spectra. However, when only blue, and no fin, whales (or vice versa) were detected by analysts, there were no discernable differences in the spectral levels of different frequency ranges. This suggests that, absent other confirmation of the presence of blue and fin whale vocalizations, these species cannot be reliably discerned from spectra data alone in regions and seasons where the two overlap.

15. SUBJECT TERMS
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Contents

LIST OF FIGURES ii

SHORT-TERM DEPLOYMENT IN AND NEAR THE NORTHERN EDGE RANGE. 1
Recovery 4

LONG-TERM MONITORING OF BLUE AND FIN WHALE ACOUSTIC SIGNALS FROM THE NORTH PACIFIC 1994-2009: COMPARISON OF DATA FROM SPECTRA AND ANALYST-DERIVED IDENTIFICATIONS. 10

LITERATURE CITED 21

INITIAL DISTRIBUTION LIST 25

<u>**List of Figures**</u>

Figure 1:	Northern Edge region shown as polygon in the northeastern Gulf of Alaska. Proposed locations of recording packages are shown as dots.	2
Figure 2:	Actual locations of instruments deployed in the Gulf of Alaska.	3
Figure 3:	Number of high and moderate quality porpoise click train detections from NE1.	4
Figure 4:	Number of high and moderate quality dolphin click train detections from NE1.	5
Figure 5:	Click trains recorded at NE1 (high and moderate quality combined) that resemble echosounders from ships.	6
Figure 6:	Click trains (high and moderate combined) recorded at NE1 that are similar to known trains from dolphins or porpoises, but for which identification is not known.	7
Figure 7:	Number of high and moderate quality porpoise click train detections from NE2.	7
Figure 8:	Number of high and moderate quality dolphin click train detections from NE2.	8
Figure 9:	Click train recorded at NE2 (high and moderate quality combined) that resemble echosounders from ships.	8
Figure 10:	Click trains (high and moderate combined) recorded at NE2 that are similar to known trains from dolphins or porpoises, but for which identification is not known.	9
Figure 11:	Map of FICTIVE instrument locations.	12
Figure 12:	Long-term spectrogram of 10-50 Hz from site K.	13
Figure 13:	Western Pacific blue whale detections (solid blue line) and relative sound levels for 18-20 Hz from spectra derived from Figure 12 for site K.	14
Figure 14:	Fin whale detections (solid red line) and relative sound levels for 16-25 Hz from spectra derived from Figure 12 for site K.	14

List of Figures *(cont.)*

Figure 15:	Long-term spectrogram of 10-50 Hz from site J.	15
Figure 16:	Western Pacific blue whale detections (solid blue line) and relative sound levels for 18-20 Hz from spectra derived from Figure 15 for site J.	15
Figure 17:	Fin whale detections (solid red line) and relative sound levels for 15-17 Hz and 21-25 Hz from spectra derived from Figure 15 for site J.	16
Figure 18:	Long-term spectrogram of 10-50 Hz from Site G.	17
Figure 19:	Eastern Pacific blue whale detections (solid blue line) and relative sound levels for 16-17 Hz from spectra derived from Figure 18 for site G.	17
Figure 20:	Fin whale detections (solid red line) and relative sound levels for 18-25 Hz from spectra derived from Figure 18 for site G.	18
Figure 21:	Long-term spectrum of 10-50 Hz from Site O.	19
Figure 22:	Eastern Pacific blue whale detections (solid blue line) and relative sound levels for 16-18 Hz from spectra derived from Figure 21 for site O.	19
Figure 23:	Fin whale detections (solid red line) and relative sound levels for 15-25 Hz from spectra derived from Figure 21 for site O.	20

Monitoring cetaceans in the North Pacific: analysis of retrospective SOSUS data and acoustic detection on the Northern Edge Range

Final report for N00244-08-1-0036

Kathleen Stafford, Applied Physics Laboratory, University of Washington

U.S. environmental laws, including the Endangered Species Act, the Marine Mammal Protection Act, and the National Environmental Policy Act, require the Navy to conduct training operations so as to minimize impacts on marine mammals and to mitigate any adverse impacts those operations might have. The Navy maintains numerous offshore ranges in the North Pacific wherein readiness training operations are regularly conducted. One of these, the Northern Edge Range (NER), is an area in the northern Gulf of Alaska having boundaries that can change depending upon the goals of the annual exercise. Recent litigation in southern California and Hawaii severely curtailed these operations, and the U.S. Supreme Court is due to rule on the use of mid-frequency SONAR off California (Weiss 2008).

Over the past decade, the Navy (CNO N45 and ONR) in cooperation with the National Oceanic and Atmospheric Administration (NOAA) has increasingly relied on acoustic detection and tracking methods for marine mammal monitoring and mitigation. The reliance on acoustic tools is due in part to the development of the necessary hardware and software, and in part to the capability of passive acoustics to detect animals underwater, to work at night and in poor weather, and to record the relevant signals and post-process them if necessary. In the North Pacific, much of what we know about large whale seasonal occurrence comes from "dual use" of Sound Surveillance System arrays (Nishimura and Conlon 1994; Moore *et al.* 1998; Watkins *et al.* 2000b; Stafford *et al.* 2001). While the SOSUS provides a broad basin-scale assessment of large whale seasonal occurrence, it cannot provide detail at the regional level, and, due to the placement of SOSUS assets, cannot provide useful information for the northern Gulf of Alaska.

This report presents data from long-term acoustic observations (15 years) of basin-wide data, as well as a very short-term, nearshore acoustic deployment.

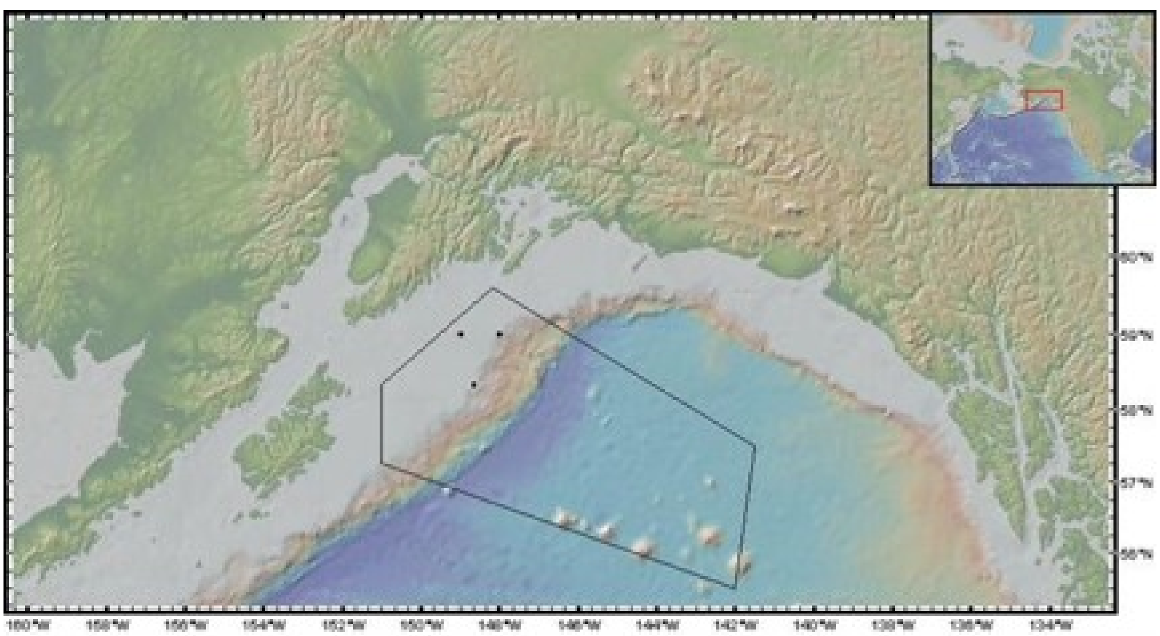
Short-term deployment in and near the Northern Edge Range

The northern Gulf of Alaska is home to many species of marine mammal including endangered blue (*Balaenoptera musculus*), fin (*B. physalus*), humpback (*Megaptera noveaengliae*), sei (*B. borealis*), right (*Eubalaena japonica*) and sperm (*Physeter macrocephalus*) whales. Additionally, numerous odontocete species, including several species of beaked whale, are known to occur here. The Northern Edge training range encompasses almost 150,000 km^2 and includes nearshore and deep water habitats (Figure 1).

Although the footprint for the Northern Edge training area is somewhat mobile, operations are generally conducted south of the Kenai Peninsula (Figure 1). From the EA/OEA for the 2004 Fleet Training Exercise (Anonymous 2004), the Purpose and Need for training in this area is as follows:

> *The increasingly diverse nature of military operations, both in peacetime and in war, demands that periodic training exercises be conducted to ensure readiness and preparedness to achieve the mission. The purpose of this exercise is to provide training and assessment procedures and coordination with a goal of improving readiness for actual operations. The Action Proponent needs to use NORTHERN EDGE 2004 to exercise and train to its mission. The Gulf of Alaska offers geographical characteristics that support training objectives established by PACOM.*

To determine seasonal occurrence of both baleen (low-frequency) and toothed (high frequency) whales in the Northern Edge training area and during the time of year when the exercises traditionally take place, passive acoustic recording instruments were deployed in the northern Gulf of Alaska. The original intent of the deployment was to compare acoustic data acquired before, during, and after these exercises to document vocal species present in the region over the time frame monitored. However, as in past years, offshore exercises as part of the biennial Northern Edge operations were cancelled shortly before the marine mammal monitoring instrumentation was to be deployed, which made one of the main goals of this deployment – a pre-, during-, and post-exercise comparison of whale occurrence-- impossible. We therefore focused on documenting which species (or families from the C-POD data) were vocally active on the recordings from 4 April 2010 to 15 May 2010.



<u>Figure 1.</u> Northern Edge region shown as polygon in the northeastern Gulf of Alaska. Proposed locations of recording packages are shown as dots.

Two types of instruments were deployed on moorings to monitor the acoustic environment of the nearshore Gulf of Alaska in the NER. The first, for baleen whales, consisted of a recorder developed for use in Acoustic Sea Gliders (ASG) (Moore *et al.* 2007) that sampled at 5 kHz with a low-pass at 1.2 kHz and C-PODs (Trengenza 2006). The advantage of C-PODS over simple recorders is that they sample continuously but do not log time series, so the recording duration of a single instrument is much greater than that of a recorder. Because only detections are logged, there is no need to subsample or set a duty cycle for monitoring for odontocetes such as beaked whales. The disadvantage of this system is that *a priori* knowledge of the species-specific frequency bands of interest is required.

Three moorings, each consisting of an anchor, ORE coastal acoustic release transponder (CART), a C-POD and hydrophone package as well as flotation, were assembled to be deployed in the NER, with two near the shelf break to listen for beaked whales and the third on the inner shelf to monitor near-shore animals such as killer and humpback whales. All three moorings were deployed from the *M/V Dora* out of Seward, Alaska, on 3-4 April 2010. Right before the scheduled deployment, it was learned that the U.S. Navy would not be participating in the 2010 NE exercise. This, combined with a truly miserable offshore forecast for the northern Gulf, caused us to move the deployment locations closer to shore such that two were in the bounds of the NER and one (a control) was inshore of the NER (Figure 2).

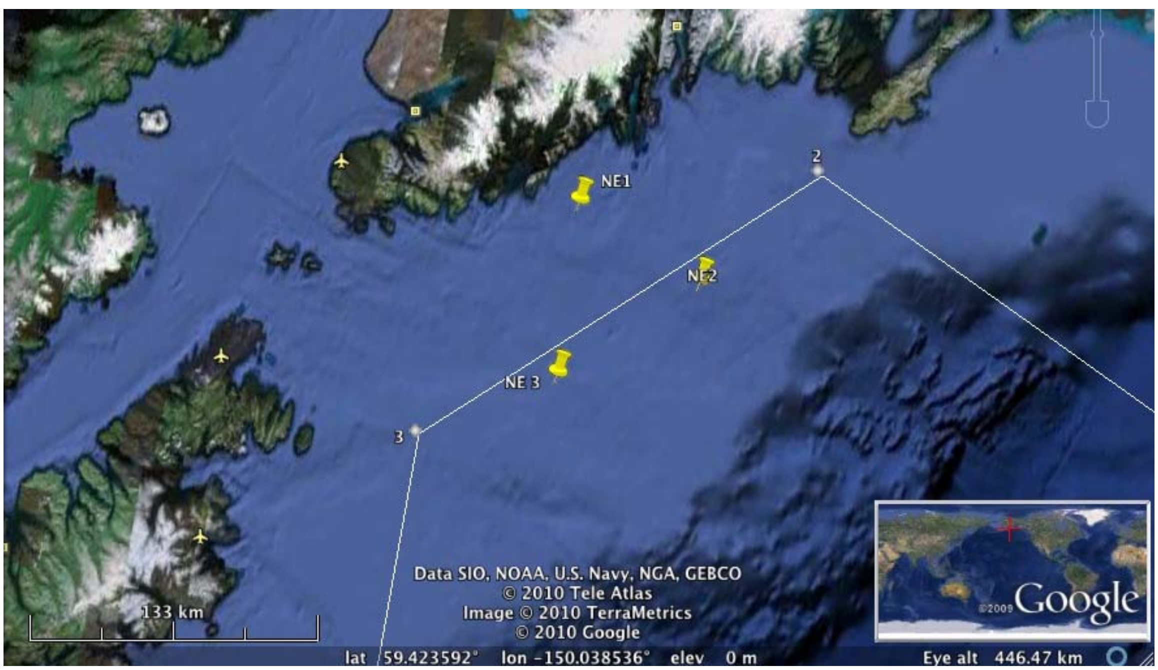


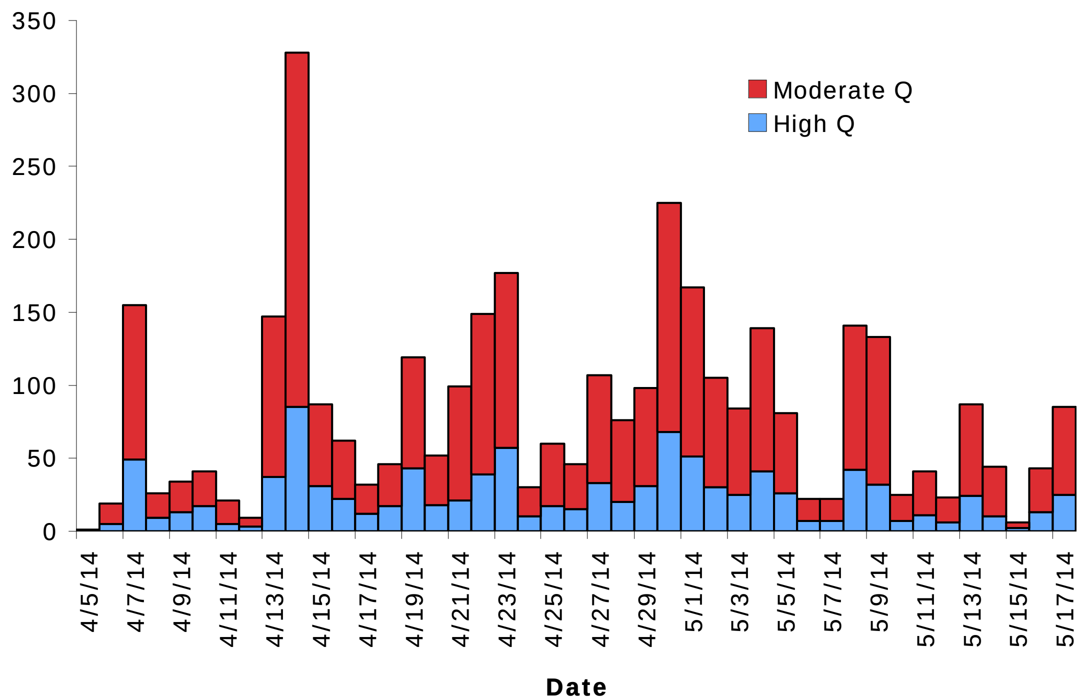
Figure 2. **Actual locations of instruments deployed in the Gulf of Alaska. Instruments were moved closer to shore due to poor weather conditions that precluded deployments near the shelf break.**

Recovery

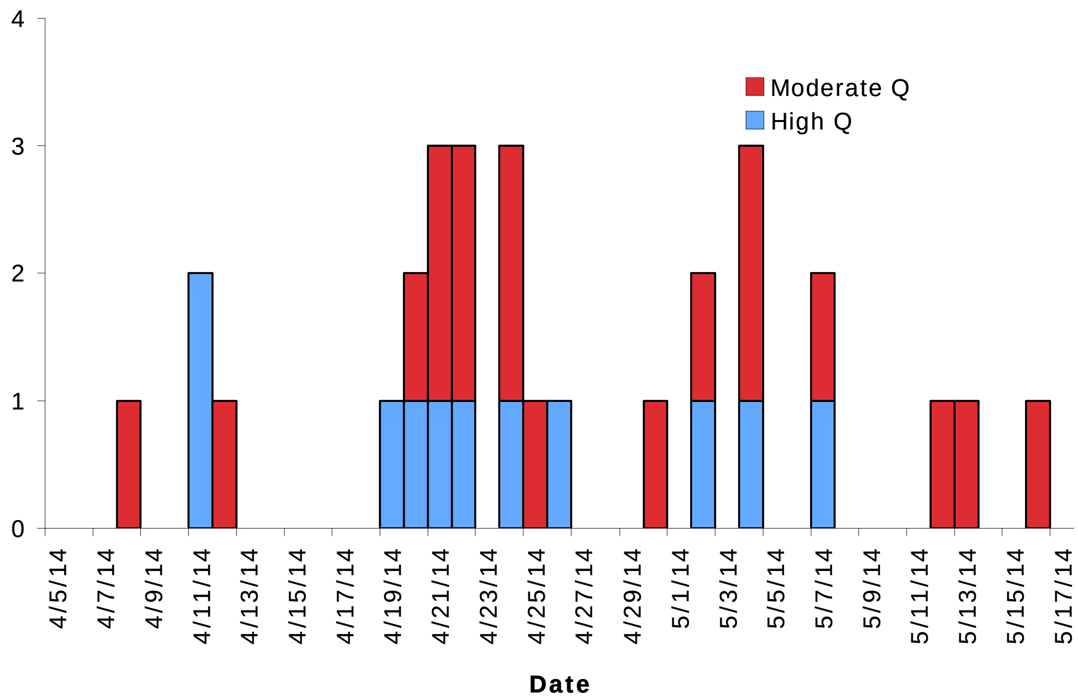
All three moorings were safely recovered on 15-16 May 2010 from the *R/V Pandalus* in horrific weather conditions.

One of the three low-frequency recorders had a corrupt CF card upon retrieval. No baleen whale calls were detected on the other two low-frequency recorders during the deployment period. Each of these instruments had their gain set very low so distant animals, if they were vocal, were unlikely to be detected. As there was no co-incident visual survey, it is unknown whether whales were present in the area, although a few fin whales were seen near NE2 during the deployment cruise.

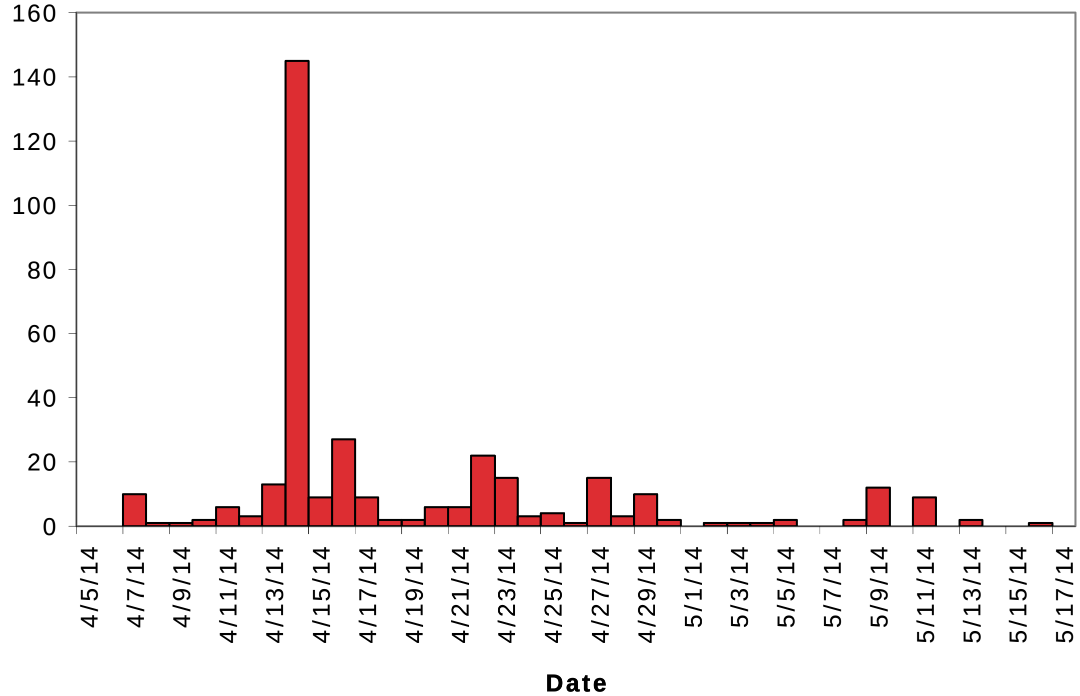
Of the three C-Pods deployed, one (NE3) had problems due to a software glitch that caused it to freeze up 90 minutes after deployment. The other two logged for the entire duration of the deployment. Figures 3-10 show the number of click trains detected by day by porpoises, dolphin species, boat sonars (echosounders) and unknown sources.



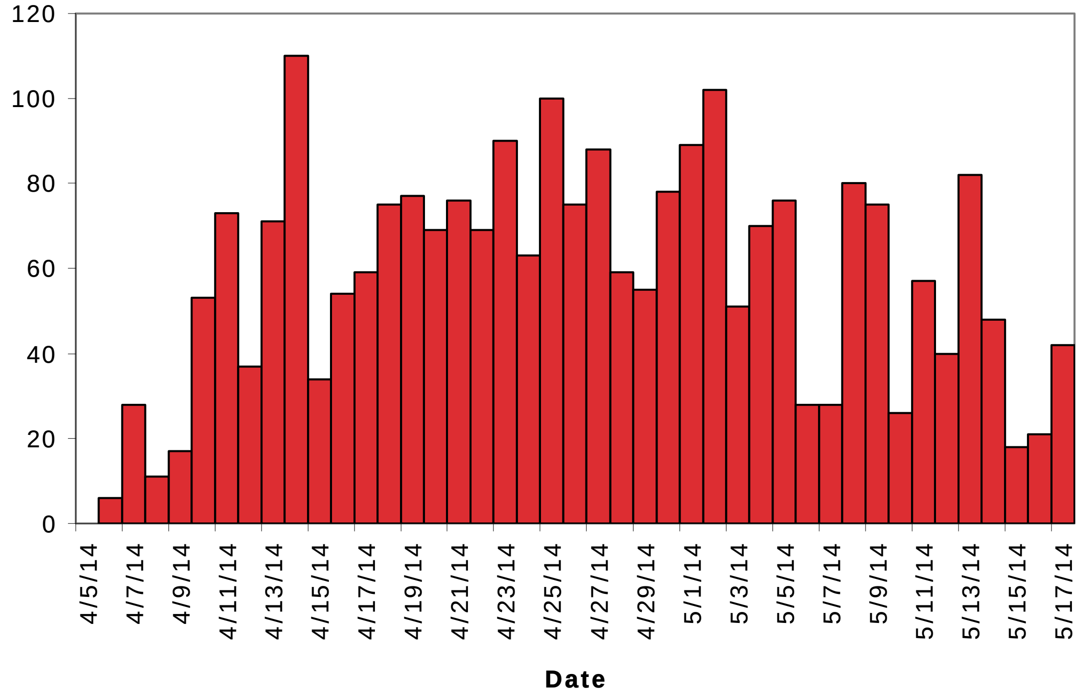
<u>Figure 3.</u> Number of high and moderate quality porpoise click train detections from NE 1.



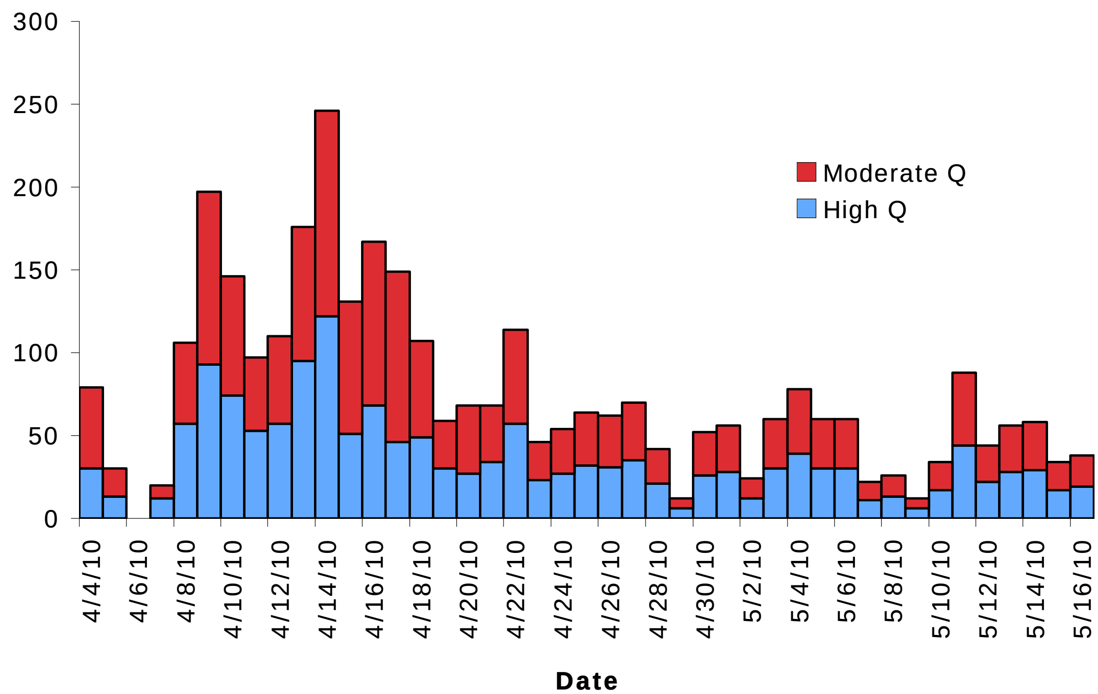
<u>Figure 4.</u> Number of high and moderate quality dolphin click train detections from NE1.



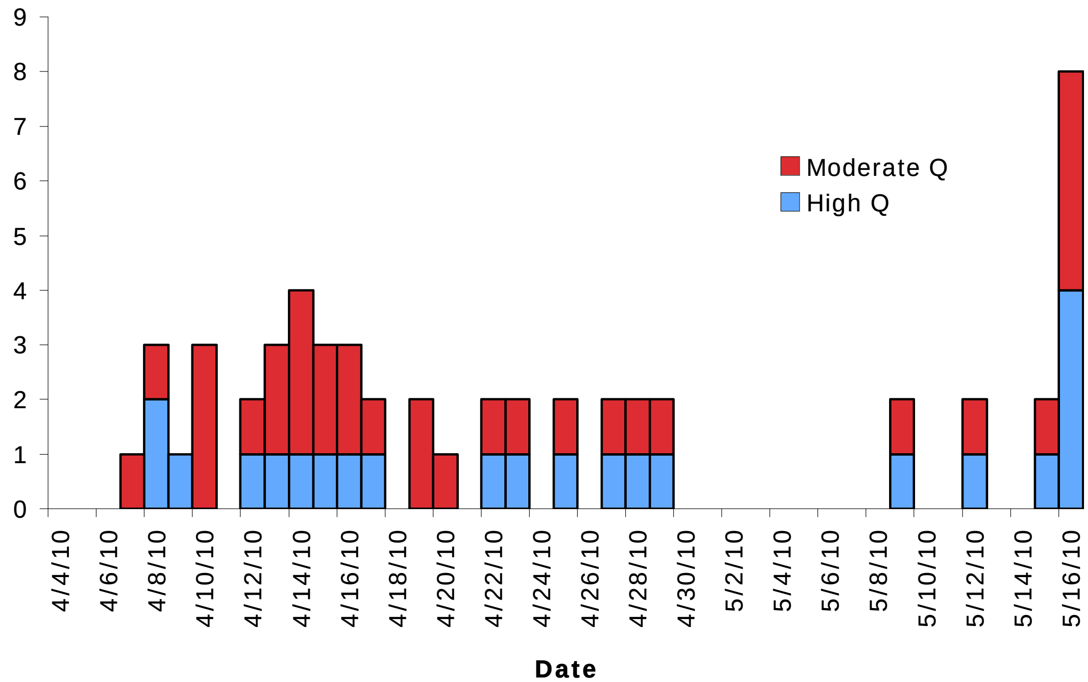
<u>Figure 5.</u> Click trains recorded at NE1 (high and moderate quality combined) that resemble echosounders from ships.



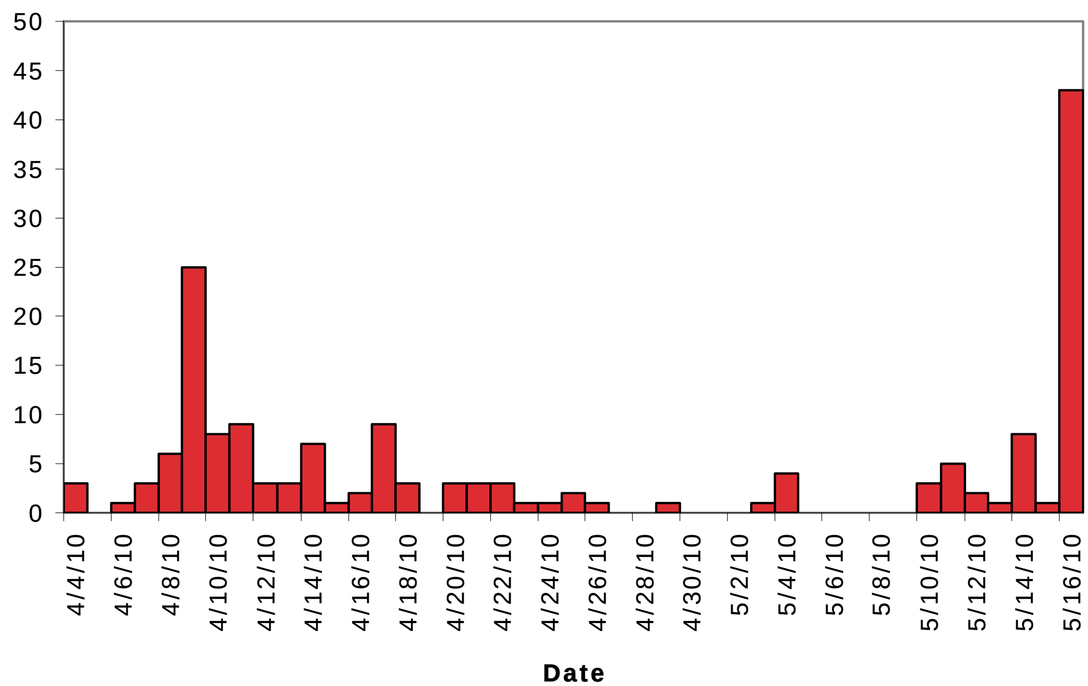
<u>Figure 6.</u> **Click trains (high and moderate combined) recorded at NE1 that are similar to known trains from dolphins or porpoises, but for which identification is not known.**



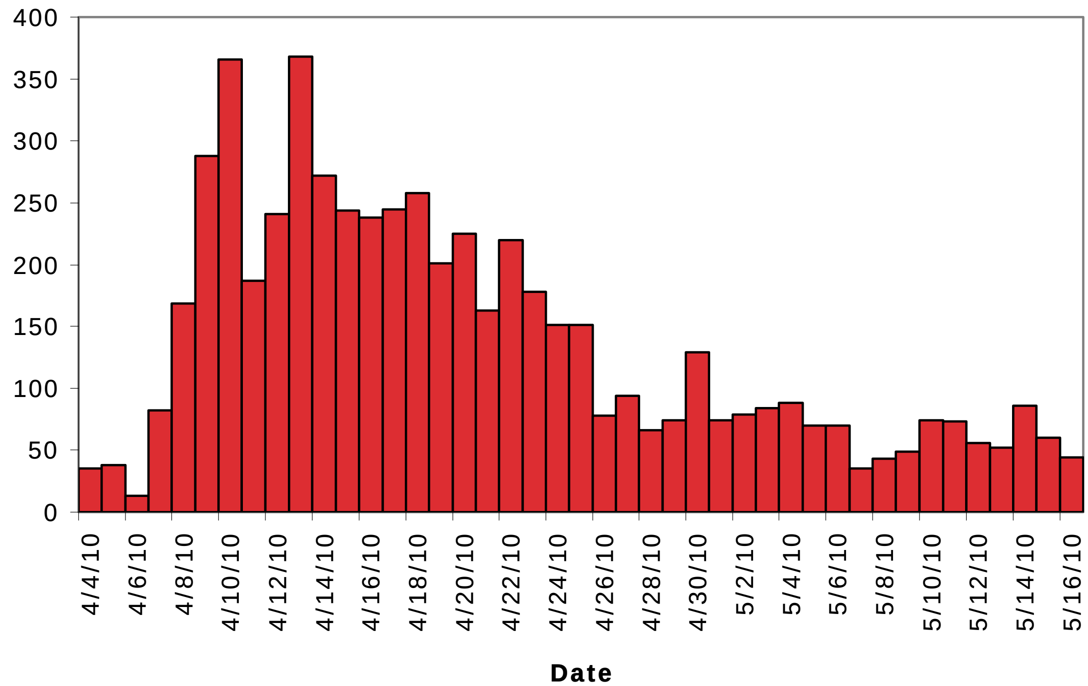
<u>Figure 7.</u> **Number of high and moderate quality porpoise click train detections from NE 2.**



<u>Figure 8.</u> Number of high and moderate quality dolphin click train detections from NE 2.



<u>Figure 9.</u> Click trains recorded at NE2 (high and moderate quality combined) that resemble echosounders from ships.



<u>Figure 10.</u> Click trains (high and moderate combined) recorded at NE2 that are similar to known trains from dolphins or porpoises, but for which identification is not known.

A combined visual-acoustic survey was conducted by the National Marine Mammal Laboratory in April 2009 to provide estimates of abundance (when possible) or document the presence of marine mammals in the Northern Edge Range (Rone *et al.* 2010). During that survey, 11 different species of marine mammal were seen, but only sperm and killer whales were heard. As with that study, we did not detect any baleen whales on the two low-frequency recorders that functioned. Although many baleen whale species produce sounds year-round, the repetitive "songs" of large whales are most often recorded in winter months, even at high latitudes, and decrease in spring (Clark and Clapham 2004, Širović *et al.* 2004, Stafford *et al.* 2007). It is not, therefore, that surprising that we did not detect the sounds of baleen whales during our short-term, spring time deployment.

The two C-PODs that functioned correctly were both relatively nearshore, with NE1 closer to shore and outside of the designated NER area. NE2, while also in shallow water, was in the NER area. Both of these instruments had 10s to 100s of porpoise-like click trains detected daily. Dolphin-like click train detections were an order of magnitude lower, but were detected nearly every day. In the NER, we expect that the porpoise signals came primarily from harbor (*Phocoena phocoena*) and Dall's porpoise (*Phocoenoides dalli*), both of which are common to the region. The dolphin signals could have come from Pacific white-sided dolphins (*Lagenorhynchus obliquidens*) and killer whales (*Orcinus orca*), which are the most common delphinids in the area. Clearly visual ground-truthing of species present is important to determine which of these (or other) species were the source of the dolphin-like click trains. Nevertheless, odontocete cetaceans were detected daily within, and just shoreward of, the NER in April and May 2010.

Our C-PODs were not far enough offshore to detect the signals of beaked whales; but neither did the 2009 visual survey see any. There were, however, many click trains detected that may belong to as-yet-unidentified species. The C-POD software is based on the time and frequency characteristics of known species, such as harbor porpoise and beluga whales, and is constantly being adapted to identify other odontocetes. Although our instruments were in much shallower water than that in which beaked whales are found, these instruments may prove useful in the future for the detection of beaked whales in remote areas.

The NER has been little used in the past decade for active Navy exercises, unlike ranges off southern California, Hawaii and the Bahamas. Because this area is relatively remote and subject to much worse weather, there are few recent studies of the seasonal occurrence of marine mammals in this area. In order to obtain estimates of number of species and their residence time in both the near and off shore Gulf of Alaska, it is clear that a combination of acoustic and visual data are needed to better assess the suite of species (vocally active and silent) in a region that may be used as an offshore training range for Naval exercises.

Long-term monitoring of blue and fin whale acoustic signals from the North Pacific 1994-2009: comparison of data from spectra and analyst-derived identifications

Blue (*Balaenoptera musculus*) and fin (*B. physalus*) whales are highly mobile, pelagic whale species that occupy all ocean basins. As the largest whales in the North Pacific Ocean, they were also preferred targets for commercial whalers and thus two of the species to be most depleted by modern whaling methods (Perry *et al.* 1999, Guénette and Salter 2005). Both species have been protected globally for over 25 years (blue whales since 1966 and fin whales since 1981).

One means of studying blue and fin whales is via acoustic sampling from deep offshore waters of the North Pacific Ocean (e.g., Watkins *et al.* 2000a). Vocalizations of both species have the lowest frequency of all cetaceans and are produced in roughly the same bandwidth, 15-30 Hz fundamental frequencies (Mellinger *et al.* 2007). Fortunately, vocalizations are readily distinguishable between fin (Watkins 1981, Watkins *et al.* 1987) and blue whales (Thompson *et al.* 1996, Rivers 1997), as well as among different populations of blue whales (Stafford *et al.* 2001, McDonald *et al.* 2006). Consequently, vocalizations can be used to investigate the seasonal occurrence of these two species.

Blue whales in the eastern North Pacific are the best studied of all extant populations of this species. Visual surveys (Barlow 1995, Barlow and Forney 2007, Calambokidis and Barlow 2004) have provided detailed accounts of blue whale distribution and abundance, while passive acoustic and satellite telemetry data have documented seasonal migrations from California to the Costa Rica Dome (Mate *et al.* 1999, Stafford *et al.* 1999). Numerous acoustic studies (McDonald *et al.* 1995, Rivers 1997, Stafford 2003) have detailed the sounds of the eastern North Pacific population. Western Pacific blue whale calls have been less well studied: the first visual-acoustic confirmation that blue whales made these sounds came only in 2004 (Rankin *et al.* 2006), although these calls were attributed to blue whales much earlier (Thompson and Friedl 1982, Stafford *et al.* 2001). The western North Pacific call type has been recorded from the Gulf of Alaska westward to the Aleutian Islands and south to Hawaii (Northrup *et al.* 1971, Thompson and Friedl 1982, Stafford *et al.* 2001, Stafford 2003). Eastern Pacific blue whale B-calls generally sweep from 18-16 Hz during the time frame of this study, while western Pacific blue whale calls cover 20-18 Hz.

Broader basin-wide acoustic studies of blue whales describing seasonality and geographic distribution from the Aleutian Islands and Gulf of Alaska to California were provided by Stafford *et al.* (1999, 2001), Watkins *et al.* (2000a, 2000b, 2001) and Moore *et al.* (2002) using the U.S. Navy Sound Surveillance System (SOSUS) and other autonomous hydrophones deployed over large regions of the North Pacific Ocean.

Fin whales in the North Pacific produce low-frequency pulses centered at roughly 20 Hz (Watkins 1981). Pulses are produced in long-patterned sequences of singlets or doublets that are thought to be a reproductive display (Watkins *et al.* 1987), or as shorter, more variable pulses that have been associated with both feeding and transiting behavior (Watkins 1981, McDonald *et al.* 1995). Fin whale pulses in the North Pacific, while having most energy around 20 Hz, span the range of 15-40 Hz, with "regular" pulses covering 15-25 Hz (Watkins 1981).

Although recent advances in recording technology and automatic detection of whale calls have greatly expanded our understanding of the behavioral ecology of sound production by large whales (e.g., Mellinger and Clark 1997, 2000, Oleson *et al.* 2007a), ocean basin-scale monitoring began with Navy analysts painstakingly visually examining spectrograms at Naval facilities (Nishimura and Conlon 1994). In both the Atlantic and Pacific Oceans the dual use of these systems has provided information on the occurrence of vocal large whales from times and locations that would otherwise have been nearly impossible to monitor (i.e., Clark 1995, Moore *et al.* 1998, Watkins *et al.* 2000a, 2000b, Mellinger and Clark 2003, Stafford *et al.* 2001, 2009). From 1997-2002, Naval analysts examined subsets of spectrograms from SOSUS arrays. That progarm ended in 2002, but spectral data have been collected since 1995 by the North Pacific Acoustic Laboratory and housed at the Applied Physics Laboratory of the University of Washington. There have been two published studies using spectral data to study large whales in the North Pacific. The first of these (Curtis *et al.* 1999) did not distinguish between blue and fin whales, while the second (Burtenshaw *et al.* 2004) used the 3rd harmonic of blue whale B-calls to study that species in the eastern North Pacific.

Here we compare Navy-analyst dervied detections of blue and fin whales with spectral data to determine if there is a reliable way to separate the two species in the spectral data.

SOSUS data were used in two ways to examine long-term occurrence of blue and fin whale calls in the North Pacific. Raw acoustic data from these arrays and locations of most of the hydrophones remain classified. Fictive locations are shown in Figure 11, which is reproduced from Figure 1 of Curtis *et al.* (1999).

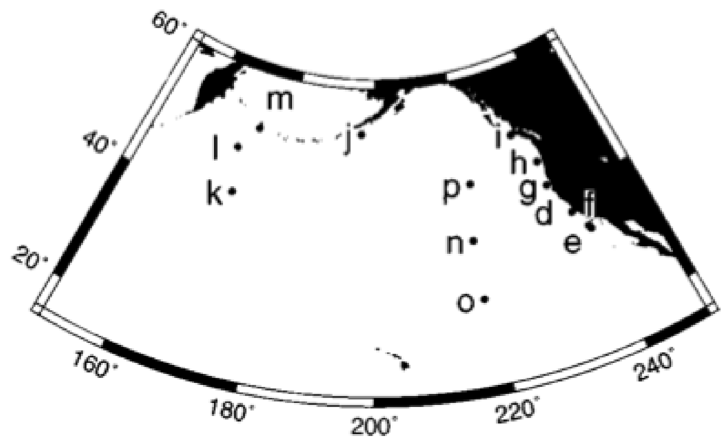


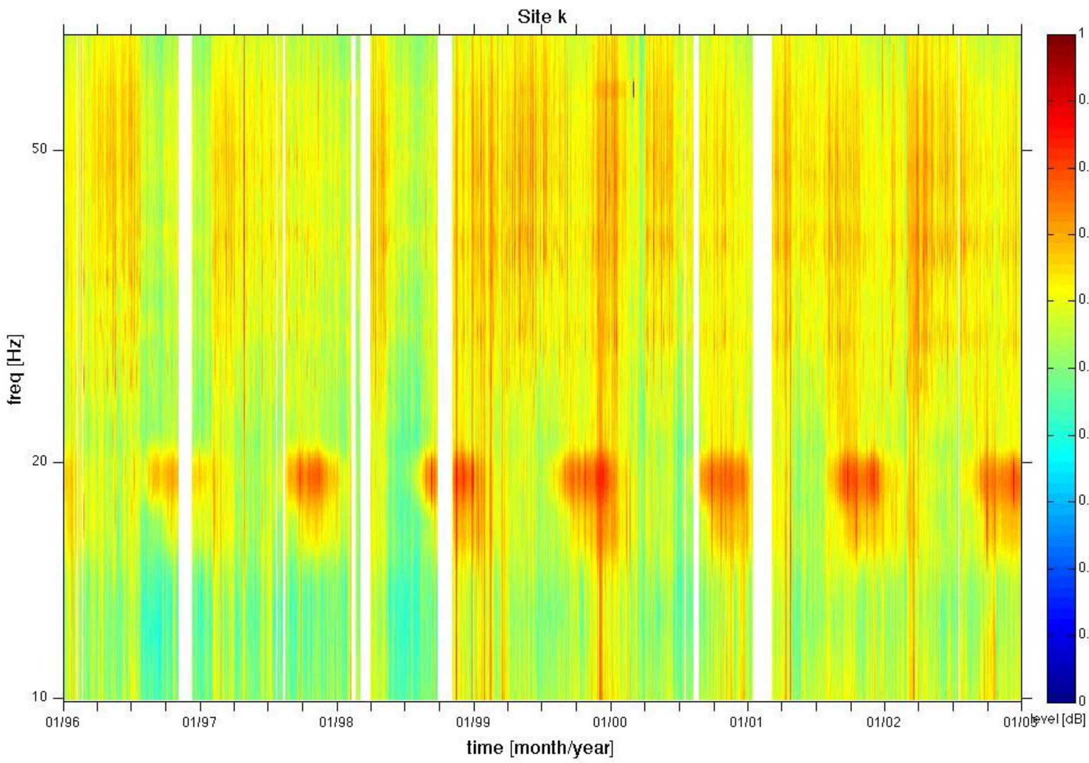
FIG. 1. Map showing the locations of receivers used in this study.

<u>Figure 11.</u> Figure reproduced from Curtis *et al.* (1999, JASA).
Map of FICTIVE instrument locations.

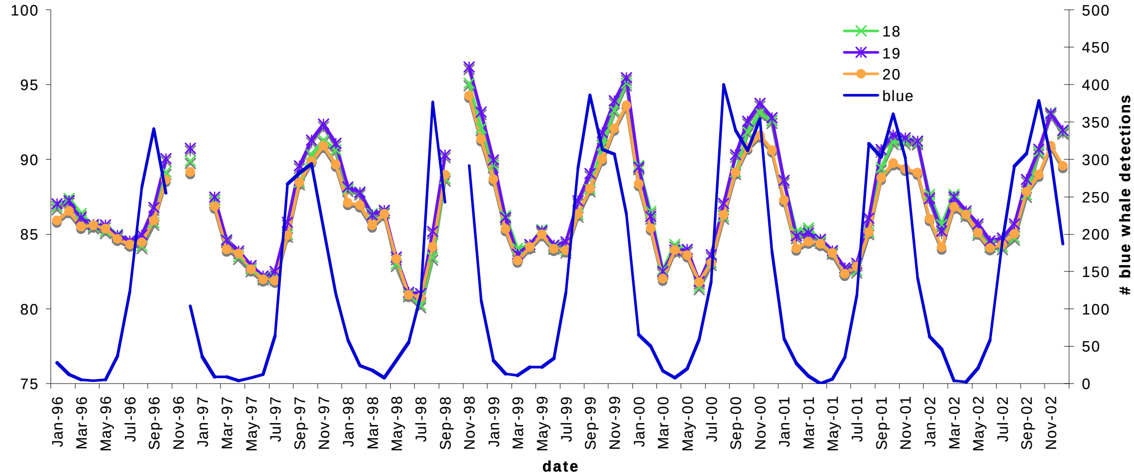
The methods used by the Navy analysts have been previously described (Watkins *et al.* 2000a, 2000b and Stafford *et al.* 2009). Briefly, calls of fin and blue whales were monitored regularly following a consistent schedule of 16 hours on each of two, usually consecutive, days every week, centered on 1200 GMT, spanning both daylight and darkness in each region, beginning in January 1996 and ending in December 2002. Data were analyzed in terms of whale call "detections" collected over the 16 consecutive hours twice a week. A call detection was defined as a call from at least one whale from the same area and direction for as long as the call(s) continued without an interruption greater than 30 minutes. Call detections by month were summed.

Likewise, the spectral data processing was described by Curtis *et al.* (1999). Those data consist of a 170-second recording every 5 minutes that is binned into 1-Hz samples, producing twelve 2-500 Hz spectral plots per hour. Because the original acoustic data from which the spectra were derived are discarded, only the relative level (dB) per 1 Hz bin is available. It is not possible to distinguish individual calls. Daily spectrograms are then produced to provide long-term looks at the contribution of whale sounds to overall ambient noise levels in the North Pacific. Data for 15-25 Hz were then extracted to better examine the blue and fin whale acoustic data. 16-18 Hz data were used for northeast Pacific blue whales, 18-20 Hz for northwest Pacific blue whales, and 20-25 Hz for fin whales (with the understanding that some contribution in the "blue whale" frequencies may be from fin whales). To match the temporal scale of the analyst data described above, the values from the spectra were averaged by month for four arrays from different regions of the North Pacific. Site K is dominated by western Pacific blue whales (that also occur at site J), while fin whales were most common at sites J, G and O. Eastern Pacific blue whales are found at sites G and O, but at relatively low levels (Watkins *et al.* 2001).

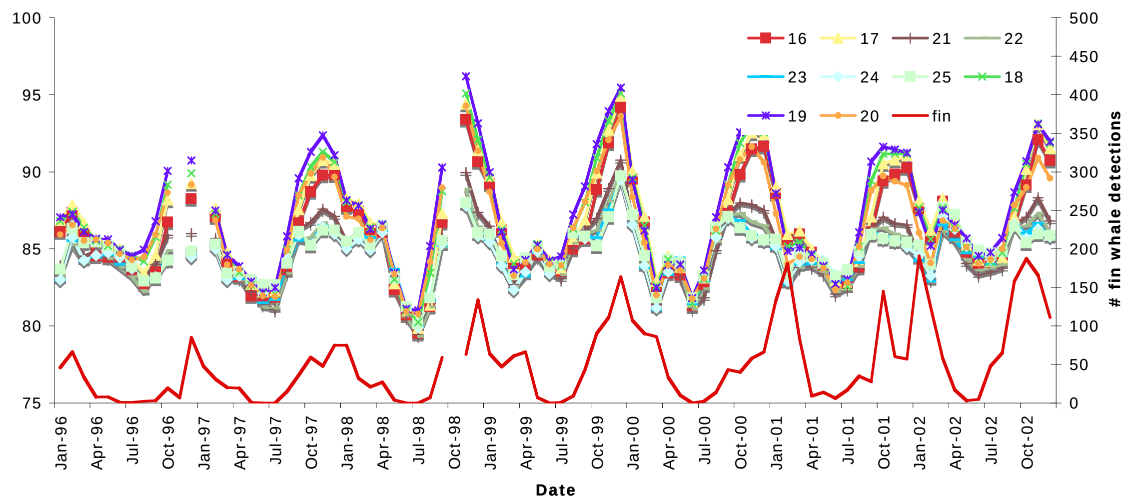
Site K is in the northwestern Pacific, where western blue whales are the predominant signal detected by analysts (Watkins *et al.* 2001, Stafford *et al.* 2009). Both blue (Figure 13) and fin (Figure 14) whales show the same seasonal pattern as the spectral data, although the peak 18-20 Hz spectra lag the analyst detections by a month. Fin whale spectra for 16-25 Hz show a similar pattern not only to analyst detections but also to blue whale spectra, although these precede fin whale spectra by about 1 month.



<u>Figure 12.</u> Long-term spectrogram of 10-50 Hz from site K. White spaces are missing data. The smears of red show the seasonal contribution of blue and fin whales to ambient noise levels.



<u>Figure 13.</u> Western Pacific blue whale detections (solid blue line) and relative sound levels for 18-20 Hz from spectra derived from Figure 12 for site K.



<u>Figure 14.</u> Fin whale detections (solid red line) and relative sound levels for 16-25 Hz from spectra derived from Figure 12 for site K.

Site J is in the north central Pacific and has many more fin whales detected than blue whales (Watkins *et al.* 2001, Stafford *et al.* 2009). Western Pacific blue whale detections (18-20 Hz) have the best correspondence with the spectra data from these frequencies (Figure 16), although the peak detections lag by about a month. The fin whale correspondence is less clean-cut. Although the time series of the two data sources show similar patterns, the analyst detections usually precede the spectra (Figure 17).

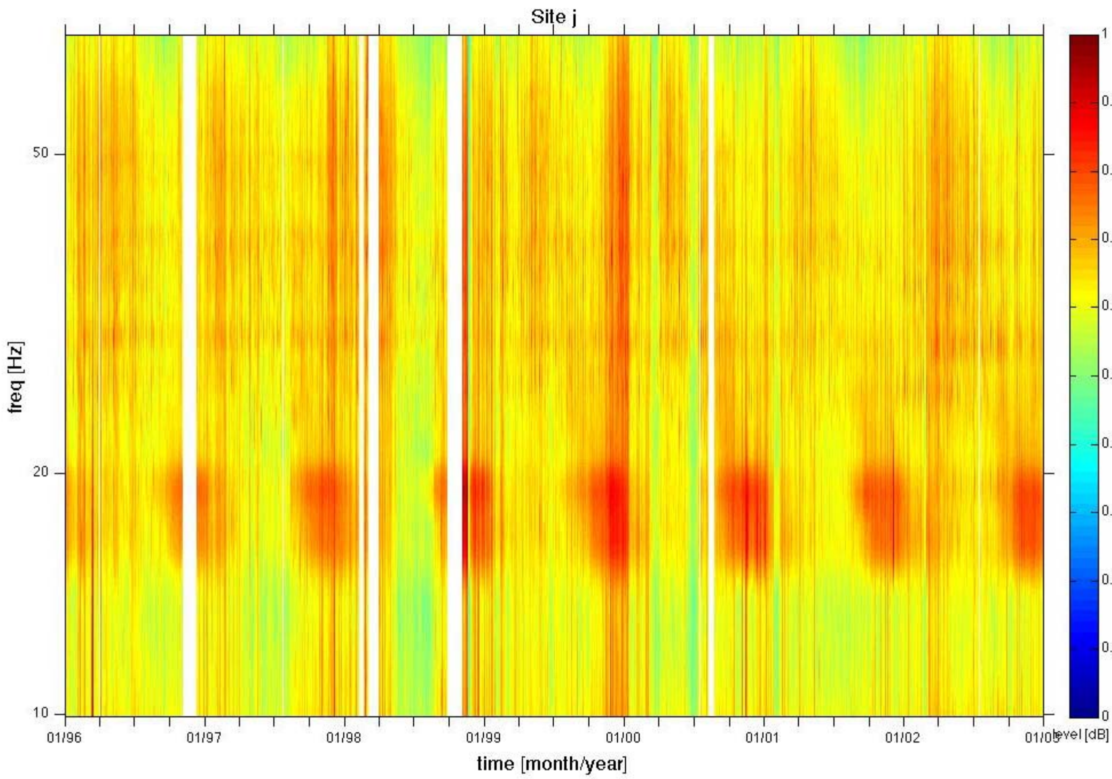


Figure 15. **Long-term spectrogram of 10-50 Hz from site J. White spaces are missing data. The smears of red show the seasonal contribution of blue and fin whales to ambient noise levels.**

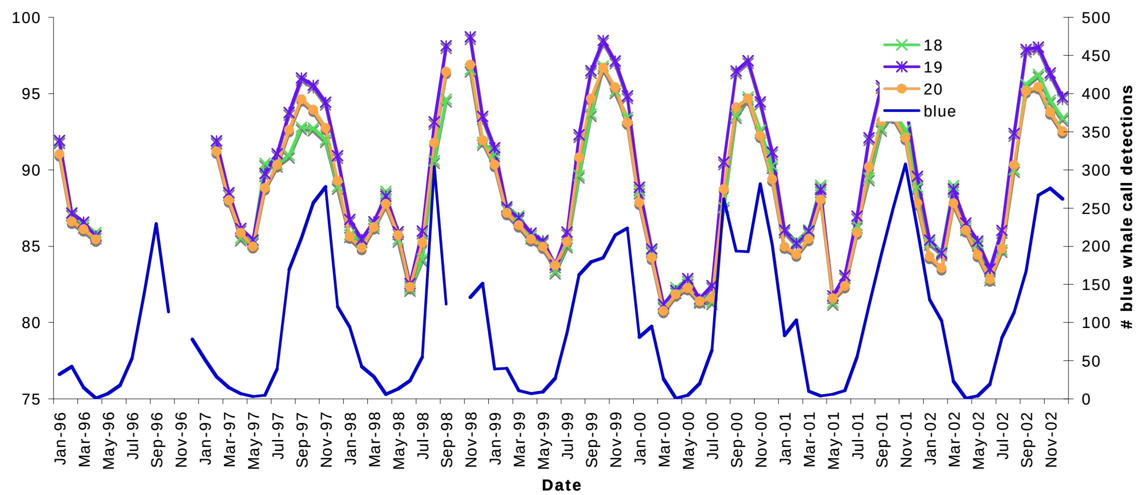
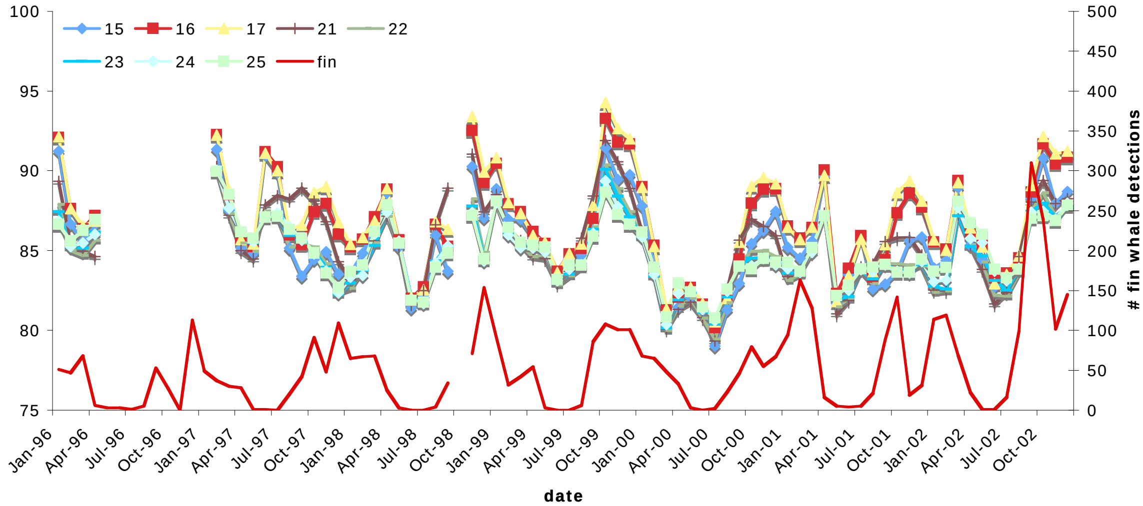


Figure 16. **Western Pacific blue whale detections (solid blue line) and relative sound levels for 18-20 Hz from spectra derived from Figure 15 for site J.**



<u>Figure 17.</u> Fin whale detections (solid red line) and relative sound levels for 15-17 Hz and 21-25 Hz from spectra derived from Figure 15 for site J.

Site G is in the northern NE Pacific. For blue whales the analyst detections always match the spectra data; but there are other, uncorrelated peaks in 16-18 Hz for this site that are not matched by analyst detections (Figure 19). For fin whales the contributions from 24 and 25 Hz match the best for this data set in terms of the “shapes” of the analyst detections and the spectral levels (Figure 20).

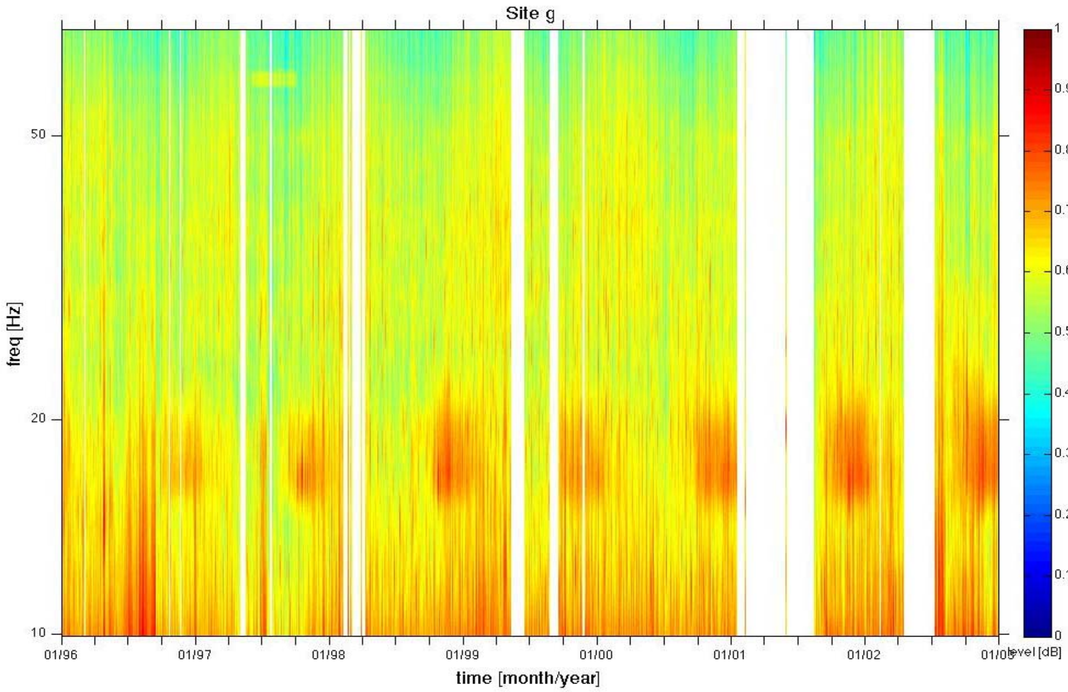


Figure 18. **Long-term spectrogram of 10-50 Hz from site G. White spaces are missing data. The smears of red show the seasonal contribution of blue and fin whales to ambient noise levels. This instrument is in the NE Pacific, but shows no evidence of 3rd harmonics of blue whale B-calls.**

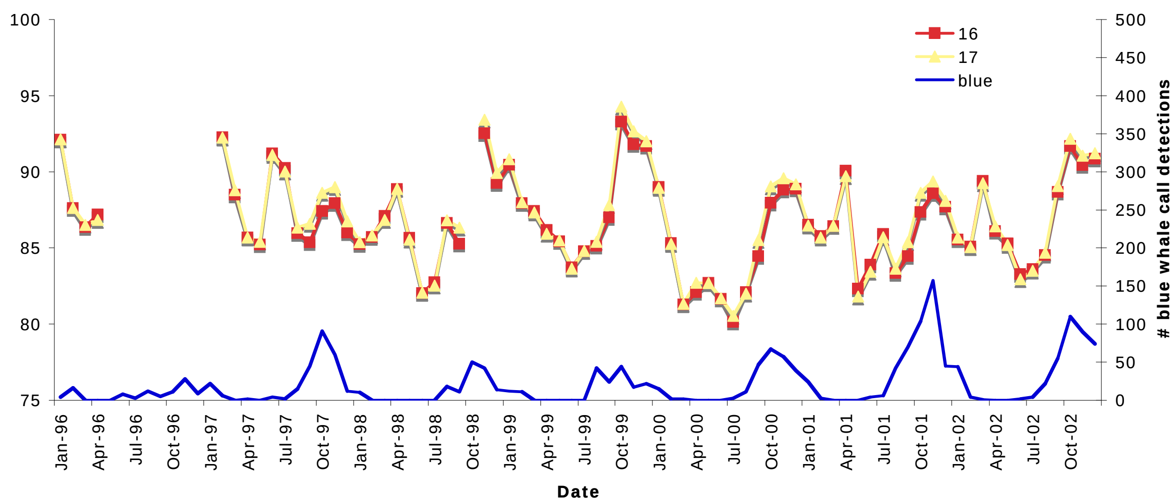
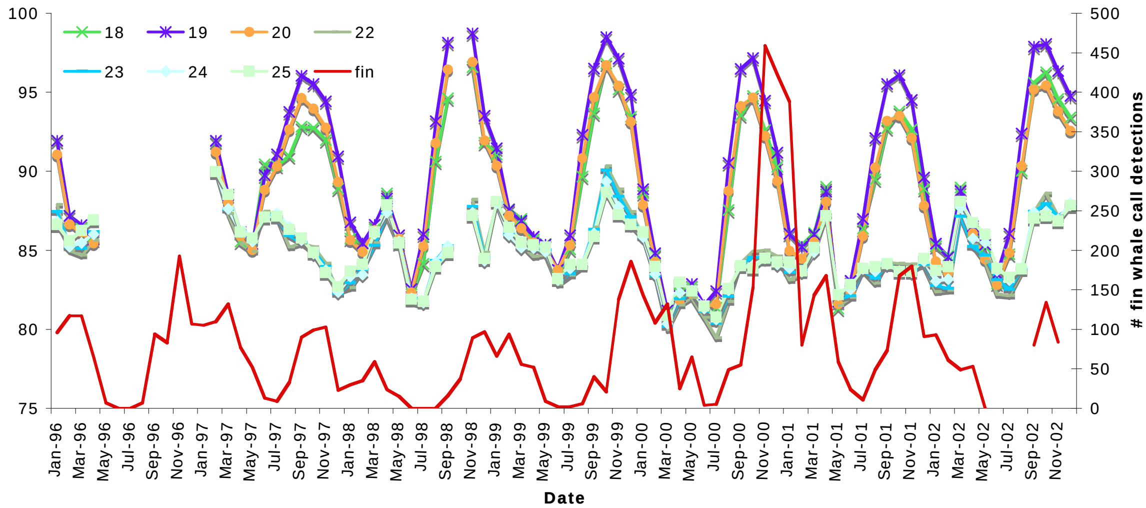


Figure 19. **Eastern Pacific blue whale detections (solid blue line) and relative sound levels for 16-17 Hz from spectra derived from Figure 18 for site G.**



<u>Figure 20.</u> Fin whale detections (solid red line) and relative sound levels for 18-25 Hz from spectra derived from Figure 18 for site G.

For site O, which is in the central North Pacific, the analyst-derived data do not match well with the spectral data. Each data source shows clear seasonal variation that is due to the presence of blue and fin whale calls; but for blue whales the spectral data peaks follow the analyst-derived detections (Figure 22), while for fin whales they precede the analyst-derived detections by up to 3 months (Figure 23).

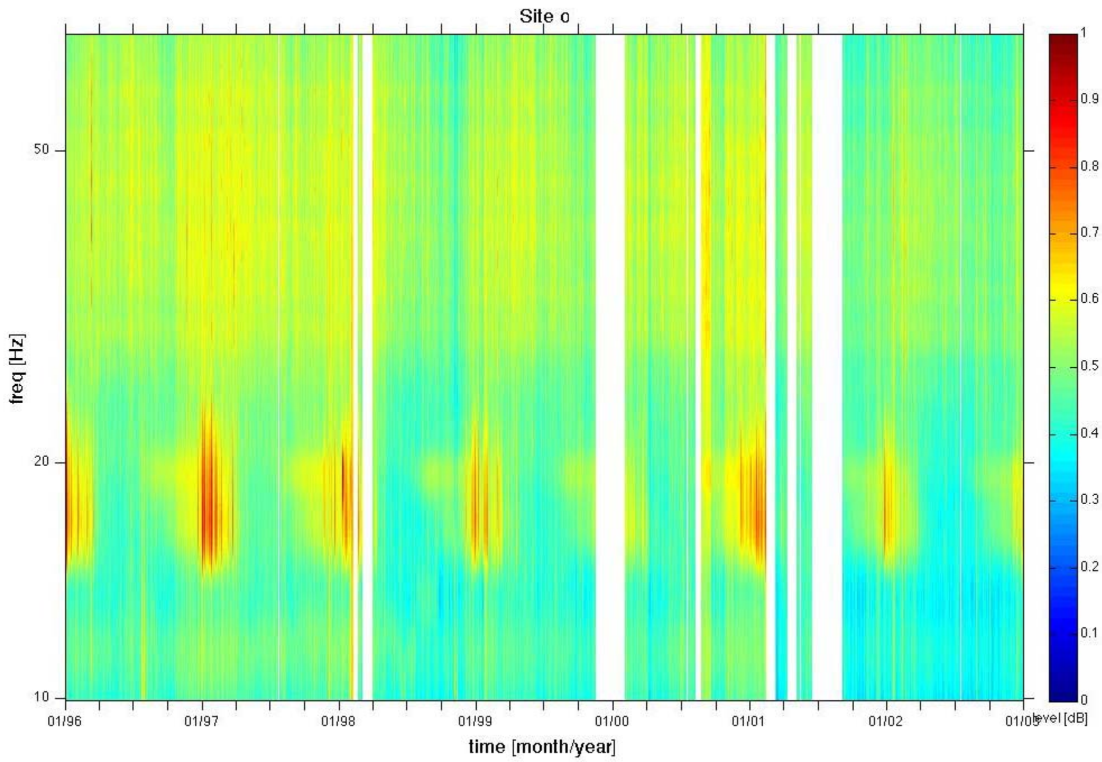


Figure 21. **Long-term spectrogram of 10-50 Hz from site O. White spaces are missing data. The smears of red show the seasonal contribution of blue and fin whales to ambient noise levels.**

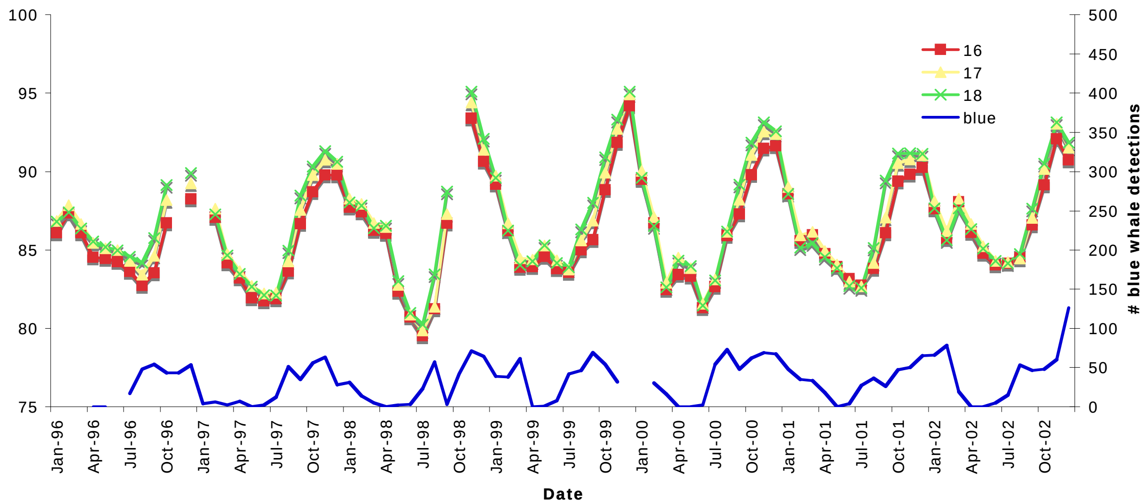
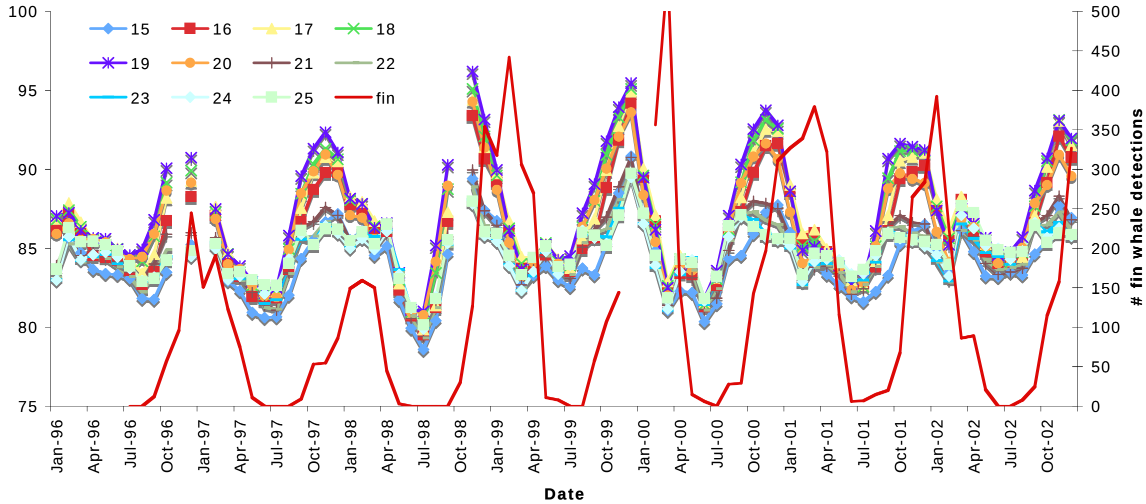


Figure 22. **Eastern Pacific blue whale detections (solid blue line) and relative sound levels for 16-18 Hz from spectra derived from Figure 21 for site O.**



<u>Figure 23.</u> Fin whale detections (solid red line) and relative sound levels for 15-25 Hz from spectra derived from Figure 21 for site O.

Overall, blue whale detections (both western and eastern North Pacific) matched the spectra for 18-20 Hz and 16-18 Hz, respectively. Fin whale detections also showed the same general pattern as the spectral data and matched the higher frequencies well, although peaks in the spectral data tended to precede those from the analysts. However, during months when only blue whales were detected by analysts and no fin whales (or vice versa), there were no discernable differences in the spectral levels of different frequency ranges. This suggests that, in the absence of other confirmation of the presence of blue and fin whale vocalizations (for instance, from sources of archived time series), these species cannot be reliably discerned from spectra data alone in regions and seasons in which the two overlap. Western Pacific blue whales produce sounds in the 18-20 Hz range, directly overlapping the "20-Hz" pulse of fin whales, and they do not generally produce harmonics (Stafford *et al.* 2001). For eastern Pacific blue whales, when present, the 3^{rd} harmonic has been successfully used to detect that species even in the presence of fin whale "noise" (Burtenshaw *et al.* 2004).

Spectral data were available hourly from each of the four sites presented here. The known fin and blue whale detections provided by Navy analysts were only available monthly. Many of the differences seen in the time series of these two data sources may be due to the averaging of the spectra data into one month bins. This provides a much coarser estimate of blue and fin whale occurrence. The overlap in frequencies used by both species makes it almost impossible to confidently distinguish between the two where higher frequency harmonics are not present (as in Burtenshaw *et al.* 2004).

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