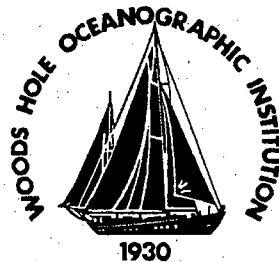


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**Woods Hole
Oceanographic
Institution**



**Distribution of Calling Blue, Fin, and Humpback Whales
in the North Pacific**

by

William A. Watkins, Mary Ann Daher,
Joseph E. George, and Scott Haga

December 2000

Technical Report

Funding was provided by the Office of Naval Research under Contract No. N00014-96-1-1130
CNO-N45 Environmental Program and
U.S. Army Corps of Engineers (DCA87-00/H-0026) with funds from
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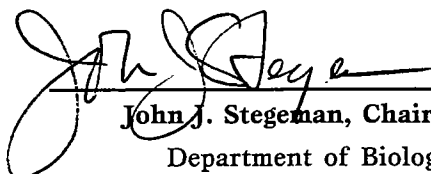
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John J. Stegeman, Chair
Department of Biology



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ABSTRACT

The seasonal distribution of calling blue whales (Balaenoptera musculus) and fin whales (B. physalus), and singing humpback whales (Megaptera novaeangliae) has been analyzed from acoustic data recorded by U.S. Navy Sound Surveillance System (SOSUS) and other hydrophone arrays in the North Pacific. The data from ten arrays were selected as representative of four Regions along the continental margins, labeled Northwest (NW), Northcentral (NC), Northeast (NE), and Southeast (SE). The call data indicate that there is a substantial population of blue whales scattered over the North Pacific and concentrated during the Fall season in the NW and NC Regions. Blue whale calls are recorded in all seasons, particularly in these NW and NC Regions. Fin whales are found in groups but also in relatively large numbers in all Regions, with most calling in the Winter season and in the NC Region, and calling is absent in most Regions during Summer. Fin whale calling includes "F" calls from individuals heard in all seasons and "J" calls from too many whales to separate, particularly prominent in the winter reproductive season. Humpback singing is recorded most in the NC and SE Regions at the time of their Winter/Spring migration. The distribution of singing humpbacks changed in both the NC and SE Regions between the 1996-1997 and 1998-2000 periods.

INTRODUCTION

The occurrence of calls from blue whales (Balaenoptera musculus) and fin whales (B. physalus), and singing by humpback whales (Megaptera novaeangliae) have been analyzed from acoustic data recorded by U.S. Navy Sound Surveillance System (SOSUS) and other hydrophone arrays in the North Pacific (Watkins et al. 2000a). Data on calling whales have been recorded over the last five years at the Naval Ocean Processing Facility, Whidbey Island. These have provided regularly updated assessments of the current distribution of the different species and the changes that occurred with season. The call occurrence data for the three whale species from November 1995 through July 1999 were presented for ten North Pacific arrays which provided representative data for four Regions along the continental margins of the North and Northeast Pacific Ocean (Watkins et al. 2000b). Descriptions of the monitoring program and the application of the data to an understanding of the distribution and seasonal acoustic behaviors of these three whale species were given by Watkins et al. (2000a and b).

The following report continues the analysis of those and succeeding data, and describes the distribution of the whale populations whose calls have been monitored across the North Pacific, focusing on the four Regions bordering the continental margins.

METHODS

Acoustic data from U.S. Navy SOSUS and other offshore hydrophone arrays in the North Pacific monitored since November 1995 were used to provide assessments of the seasonal distribution of calling blue, fin, and humpback whales. Ten bottom mounted hydrophone systems were selected as providing representative data for four offshore Regions along the continental margins, labeled Northwest (NW), Northcentral (NC), Northeast (NE), and Southeast (SE). The Regions were divided at increments of 30° Longitude by 15° Latitude. These are shown in Figure 1.

Within Regions, north-south detail was provided by the use of two or three arrays at different latitudes. Individual arrays in each Region were labeled from the north (SE1 north of SE2 in SE Region, etc.). Beam-formed data from the different hydrophone arrays were interpolated to give the equivalent of 40 line array beams for each array. This provided comparable information from all array systems, regardless of their composition. Array orientations were not considered for these analyses. Locations for many of the Navy hydrophone systems remain protected, as are their characteristics and associated data processing.

Typically, there was little overlap in the sounds of local whales recorded by the different arrays within Regions. Two arrays were used in each of the NW and NC Regions, and three arrays in the NE and SE Regions (potentially one-third more observations for the latter Regions).

The acoustic data from the arrays were monitored by analysts with extensive experience working with these Navy and other acoustic systems. The analysts also were well acquainted with the spectrographic display of beam-formed representations of the whale calls. Additionally, identification of calls were reviewed by WHOI researchers with 10 to 40 years experience with such sounds, and calls were compared with sounds in the WHOI Marine Sound Archive.

The spectrographic data from all arrays were examined systematically over the same period during two, usually consecutive, 16-hour days every week, centered on 1200 hours GMT. This period spanned both daylight and darkness in each Region. The 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. No new occurrences were logged for that beam during that day, unless it was obvious that another set of calls had begun from a markedly different distance (distinct difference in level and acoustic

pattern). Whale 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. One dominant beam displaying the calls was identified for each call occurrence. When there were six or more (often many more) calling whales from apparently the same species on one beam so that the calls were not separable, this concentrated calling noise which normally lasted for most of the day was recorded as one "J" occurrence. Traditionally, such noise was called "Jezz" by Navy analysts. When specific call sequences with acoustic patterns and spectra of the different whale species were noted, these were identified as a single call occurrence for that species. Background calling from other whales of the same species (the usual ambient) was not recorded so as to confine identification of calls to those that were most easily defined, the closest calling whales. Changes over time in the distribution of individuals and local groups of calling whales, showed the extent of their movements, over days or weeks.

WHALE SOUNDS

The calls of the different whale species that were most recognizable in the hydrophone data and that had the least potential confusion from other sounds were those (1) that were composed of prominent low frequencies (propagating well), (2) that were repetitive with tonal characteristics (distinguishable from ambient noise), and (3) that were composed of recognized call patterns (characteristic of that species). Other less repetitive and transient sounds, although recognizable, were readily masked by noise and so were not made a part of these observations. The information resulting from these analyses of the hydrophone data included species identification, occurrence of calling, call variation, and received array beam, without consideration of array orientation.

Whale calls clearly identified on spectrographic displays of the beam-formed acoustic data from the hydrophone arrays included call sequences from blue whales (Balaenoptera musculus) and fin whales (Balaenoptera physalus), as well as songs from humpback whales (Megaptera novaeangliae). Each species had different amounts of calling and variations in seasonal occurrences in each of the four Regions. Call occurrence in the different Regions for each species generally was consistent between years (although apparently shifted during El Niño and La Niña years), with similar patterns of calling recorded from

similar directions during corresponding seasons, often on equivalent array beams. Estimated numbers of calling whales were different on average for each species and varied with each season, indicating seasonal differences in the numbers of calling whales of the different species in each Region. They also were likely to be related to variations in whale behaviors with season and locality.

The calling seasons for these whales were offset from the sun/calendar year by one month: changes in whale calling throughout the year conformed to four distinct seasons, labeled Spring (March - May), Summer (June - August), Fall (September - November), and Winter (December - February).

Blue whale call sequences identified in the acoustic data were their long series of repetitive, downswept tonal calls (cf. Cummings and Thompson 1971, Rivers 1997). These calls usually had fundamental frequencies below 20 Hz and several harmonics, and they were repeated variably at 3 to 10 min intervals, often continuing over several hours. Shorter calls and call sequences from this species were not consistently separable from noise and so they were not a part of these analyses.

Blue whale calling during periods of peak calling was usually from three to eight or more whales on each array beam that received the calls-- the average during peak calling appeared to be from about five whales for each calling event,

but often there were too many whales to separate. As blue whale calling waned and again as it increased during intermediate calling periods, one to three whales were identified for each calling event. During the period of lowest calling, only one blue whale usually was evident at any one time.

Fin whale call sequences identified in the acoustic data were the repetitive, down-swept "20 Hz" pulse series (cf. Schevill et al. 1964, Watkins et al. 1987). These calls had most energy near 20 Hz, with little harmonic energy. Calls were composed of pulses of about 1 sec each, repeated regularly at rates of a few seconds in characteristic temporal patterns over periods of a day or more. The short call sequences from this species were not as easily separated from noise, and so they were not a part of these analyses. Fin whale calling analyzed here included calling 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 individual whales, unless they were relatively close to arrays.

Fin whale calling ("F" and "J" calls) during the season of peak calling usually was from one to five whales per event, averaging three fin whales calling at a time. During the intermediate calling seasons, calling was from one to three

whales. During the 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. Combining the "F" and "J" calls likely provided better assessments of the numbers of calling fin whales.

Humpback whale songs could be recognized reliably, although only the frequencies below a few hundred Hertz were typically received (cf. Payne and McVay 1971, Payne et al. 1983). Songs were heard usually from groups of whales, estimated at three or more individuals singing during each event, regardless of location or season. Singing typically lasted for several hours with little movement. Singing was usually related to the migration period, even when whales remained in the area.

Individual calling whales were likely to be associated with many more whales of each species. Little is known of the number of calling individuals that normally are associated with whale groups, or of the number of whales that accompany a calling whale of each species. Most such observations have been of inshore whale populations which may have quite different patterns of activity compared to the offshore whales. There is little reliable information about the calling patterns of these whale species in offshore waters.

DISTRIBUTION OF CALLING WHALES

The average distribution of calling blue whales and fin whales, as well as of singing humpback whales in the offshore Regions of the North Pacific was derived from the call occurrence data recorded systematically for 58 months, beginning in November 1995. These assessments were focussed particularly on the four offshore Regions along the continental shelf: Northwest, Northcentral, Northeast, and Southeast (Figure 1, for example). Short-term variability in the geographic location of the whale populations and in their seasonal occurrence was reduced by averaging the recorded number of calling events for each month over the period of monitoring. North/south differences in the local concentrations of calling whales within Regions were provided by the distinctions in call occurrence at the different arrays in each Region. Two arrays were monitored in the NW and NC Regions, and three arrays in the NE and SE Regions, potentially increasing the recorded number of calling whales in the latter regions by one-third. Arrays within Regions were numbered from the north (ie. SE1, SE2, SE3). The blue and fin whale data were consistent over the monitoring period, and had equivalent monthly effort. The humpback data were divided to show more clearly the changes that occurred in the distribution of these whales during this period.

Blue whales -- Most calling by blue whales was in the Fall, evident in all four Regions, and the lowest level of calling was in the Spring (Figure 1). The NW Region had the most calling whales, and the NE had the least. The extra monitoring array in both the NE and SE potentially added one-third more to the total average numbers of calling whales in these Regions.

In the NW Region, the call data indicated a relatively large, scattered population distributed across the entire Region. Calling blue whales were recorded from all directions at about the same rate indicating whales scattered uniformly over the whole Region. The two NW arrays showed similar characteristics and levels of calling (Figure 2), with little difference in numbers of calling whales. Blue whale calls were recorded in this Region throughout the year. Even during the Spring lowest calling period, when most of the population was presumed to have migrated out of this Region, blue whales were consistently audible. During the intermediate Winter and Summer seasons, calling gradually decreased or increased, respectively, apparently with the movement of migrating whales out of and into the Region.

The NC Region also had a significant number of calling blue whales, but they were less scattered than in the NW. During the Fall peak calling period there were considerable numbers of blue whales in the NC Region, with more calls heard in the southern

portion (Figure 3). The two arrays monitored in this Region had marked differences in numbers of calling whales, indicating fewer calling whales in the northern area. Some calling was evident throughout the year over the entire Region, including the Spring period of lowest calling. The intermediate Winter and Summer seasons had decreasing and increasing calling rates, respectively, likely related to whale migration out of and into this NC Region, as well as passage through these waters.

The NE Region had fewer calling blue whales than the other Regions. More calls were recorded in the southern portion of this Region (Figure 4), indicated by the relative difference in calling recorded by the three arrays monitored in this NE Region. The third array in this Region relative to the NW and NC potentially increased the relative call counts by one-third. As in the other Regions, most calls were recorded during the Fall season. Only small numbers of calls were noted during the Spring lowest calling season, probably indicating that most of the whales moved away during migration. The NE Region also had fewer calling whales during the Winter and Summer, fewer than in the other Regions during these intermediate calling seasons.

The SE Region had more calling blue whales than the NE, but fewer than either the NC or NW Regions. Potentially, one-third more calls were recorded by the extra array used in the SE. There were about the same numbers of calling whales recorded by

each of the arrays monitored in this region (Figure 5), indicating a broad distribution of whales across the Region. The Spring season had few calls, and Winter and Summer showed the decreasing and increasing numbers of calling whales, likely related to migration.

Fin whales -- Most calling by fin whales was in the Winter, evident in all four Regions (Figure 6). Peak calling by fin whales was offset by three months from the peak for blue whales. Fin whale calling plotted in the Figures distinguishes between "F" calls from individuals and "J" calls from too many whales to separate. Most calling fin whales were recorded in the NC (more "J" calls). The additional monitoring array in both the NE and SE potentially added one-third more to the total average numbers of calling whales in these Regions. The least calling by fin whales was in Summer. During the intermediate Spring and Fall seasons, fin whale calling decreased or increased, respectively, apparently in accordance with their level of reproductive interest (similar to the pattern of calling by this species in the Atlantic and elsewhere, Watkins 1981, Watkins et al. 1985). Calling fin whales were generally in groups, in contrast to calling recorded from individual blue whales which were broadly scattered across these Regions.

In the NW Region, the call data indicated a relatively large population of both individuals and groups of calling fin whales in both northern and southern areas, with the two NW arrays indicating similar characteristics and levels of calling (Figure 7). There was little difference in numbers of calling whales indicated by the two arrays. Fin whale calls were mostly absent from this Region during the entire Summer.

The NC Region had the most calling fin whales, with considerable numbers of both individual "F" calls and "J" calling from groups of whales. Many more calling fin whales were recorded in the northern, area of the NC Region (Figure 8). Calling from groups of whales was evident throughout the year in the northern portion of the Region, while in the southern area, calling stopped in Summer. The intermediate Spring and Fall seasons had decreasing and increasing calling rates, respectively.

The NE Region had only a few less calling fin whales than the NW and NC Regions. The extra array monitored in the NE Region potentially added one-third more calls to the total for this Region. More calls were recorded in the southern portion of this Region (Figure 9), although there were more "J" calls from concentrations of fin whales in the central area. The NE Region had fewer calling fin whales than the other Regions, regardless of the calling season.

The SE Region had about the same number of calling fin whales as the NE, fewer than either the NC or NW Regions. Potentially, one-third more calls were recorded in the SE by the extra array. Calling in the SE Region dropped during the summer, but remained relatively high much of the rest of the year (graph limited by the scale). Most calling was recorded in Winter with considerable numbers in graduated amounts during the intermediate seasons. About the same number of calling whales was recorded by the different arrays (Figure 10), indicating a broad distribution of these groups of calling fin whales across the Region.

Humpback whales -- The distribution of singing humpback whales changed somewhat after 1997. Therefore, the humpback data has been divided between the 1996-1997 and 1998-2000 periods to permit better assessment of the monthly averages for singing whales. Humpback singing often appeared to be related to the timing of their migration to and from calving areas, but not always.

The occurrence of humpback singing in the different Regions during 1996 and 1997 is portrayed in Figure 11. Only isolated songs were heard in the NW (Figure 12). A few calls were recorded in the northern part of the NC Region, apparently at

the beginning and end of migration (Figure 13). Occasional songs were recorded in the southern part of the NE Region (Figure 14). However, in the SE Region, humpback singing from a sizeable population bracketed the migration period, and they continued to sing periodically throughout the season, starting in December and ending in May. Singing in the SE began abruptly in the central area and continued in the southern area during the December to May period (Figure 15, Watkins *et al.* 2000a).

In 1998, there was a shift in the occurrence and distribution of singing humpbacks, with some areas previously occupied by singing humpbacks abandoned and increased singing in others at different seasons. The humpback song data for 1998 to 2000 is given in Figure 16. The NW Region continued to have only isolated humpback songs (Figure 17). There was an increase in singing in the northern part of the NC Region (Figure 18), and occasional songs continued to be recorded in the NE Region, now in all areas (Figure 19). In the SE Region, humpback singing still began abruptly in the central and southern areas, but delayed until January (Figure 20). Humpback songs were recorded in decreasing numbers over the season, instead of with numbers increasing again during April and May, as they were in the previous (1996-1997) years.

These data on the occurrence of calling whales show the locations and seasonal distributions of populations of blue, fin, and humpback whales. There is a substantial blue whale population scattered over the North Pacific and concentrated during the Fall season in the NW and NC Regions. In contrast, fin whales are found in groups but also in relatively large numbers in all Regions, with most calling in the Winter season. Humpback singing is recorded in the northern Regions at the beginning and end of their Winter/Spring migration season, as well as in the SE Region during the migration.

ACKNOWLEDGMENTS

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PLOTS OF THE DISTRIBUTION OF CALLING WHALES

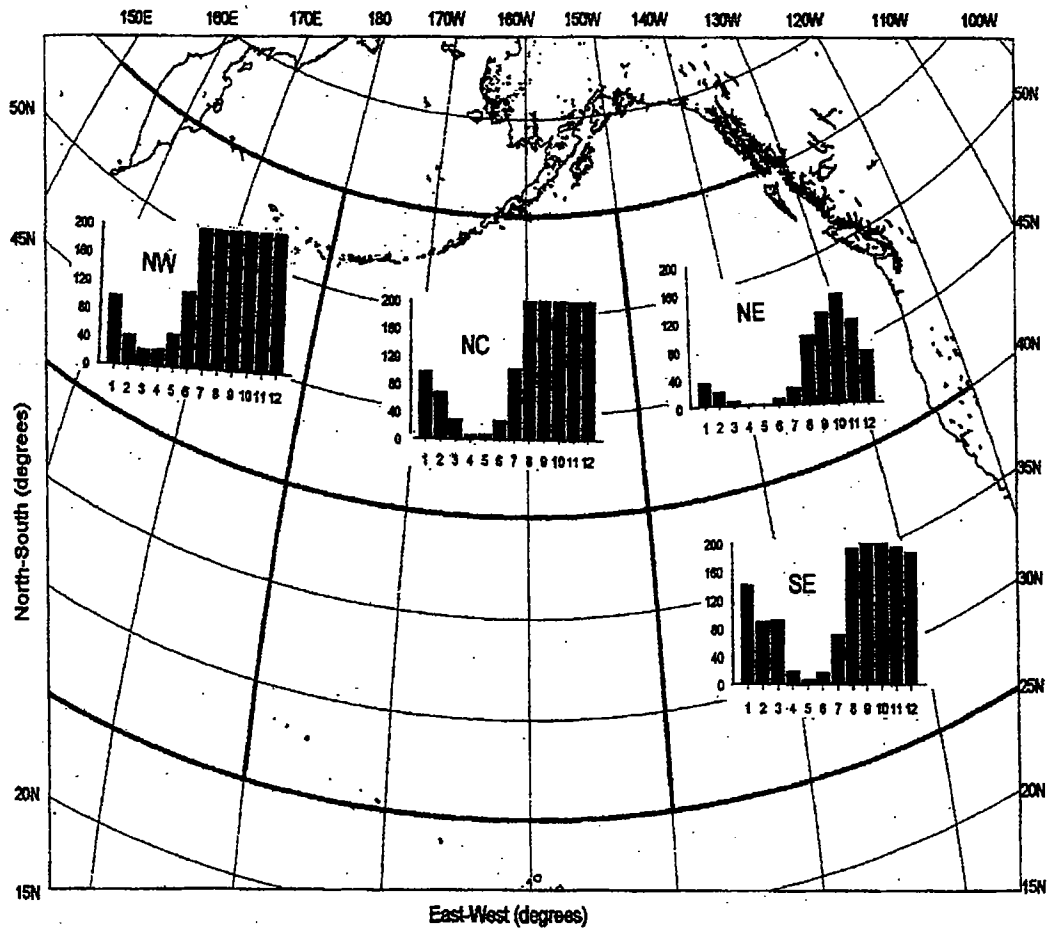
Monthly Averages by Geographic Region

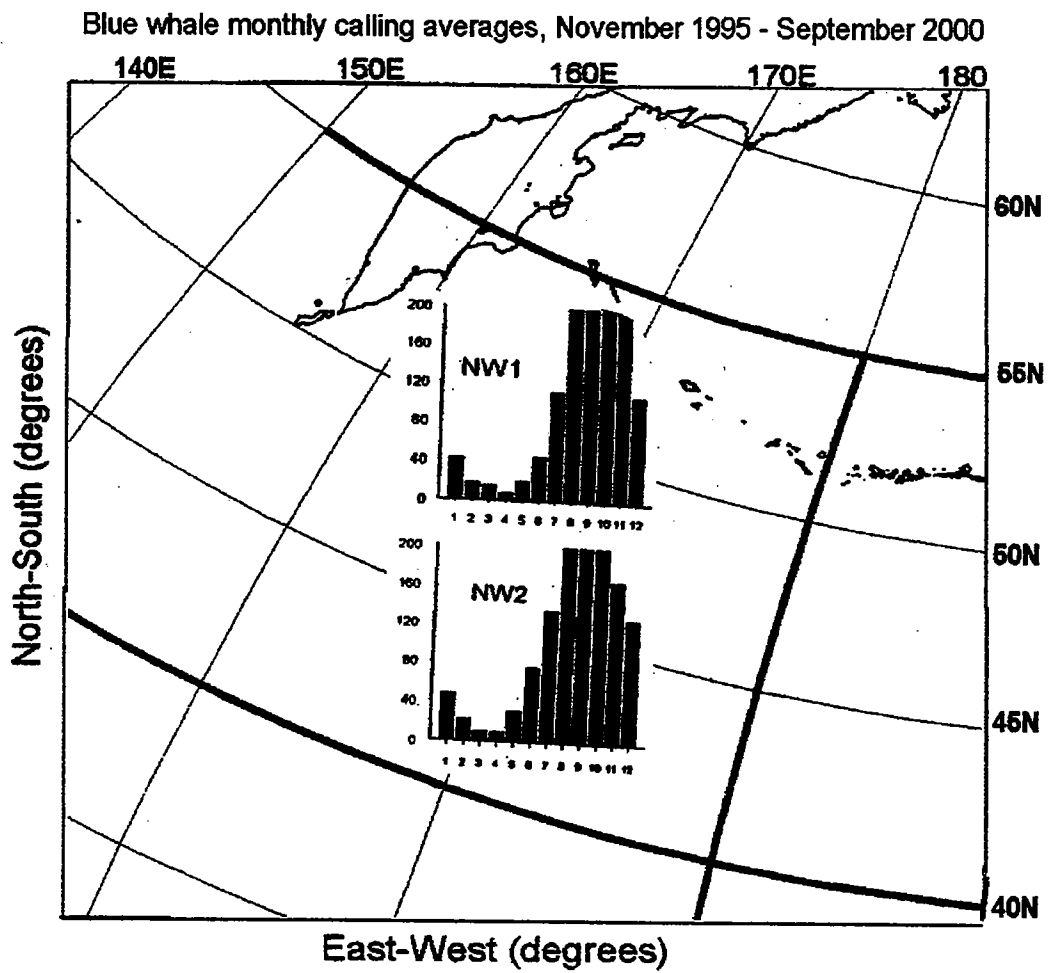
Figures 1 through 20

The occurrence of calling whales during the 16-hour two-day-per-week data sampling period has been plotted for each of the four Regions as monthly averages over the 58 months of observation. For example, Figure 1 gives the monthly average number of calling events (each includes one to eight or more calling whales): sum of all calling events identified during that month divided by the four or five years of observations. All plots are at the same scale.

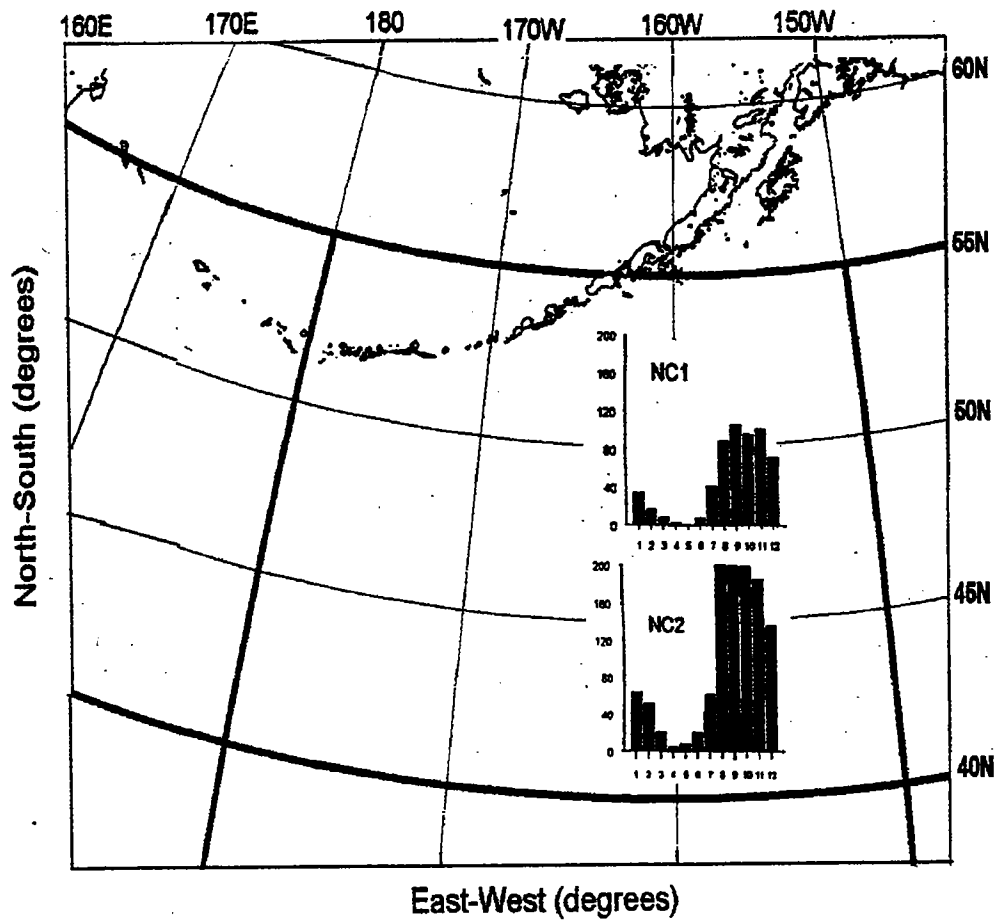
Overall averages for the four Regions are plotted in the first of a set of figures for a species (as in Figure 1 of the set of Figures 1-5 for blue whales). Then, in the succeeding Figures of the set, the data averages are plotted separately for every array monitored in each of the four Regions. Note that two arrays were monitored in the NW and NC Regions, and three arrays were used in each of the NE and SE Regions, potentially increasing the data for the two eastern arrays by one-third.

Blue whale monthly calling averages, November 1995 – September 2000

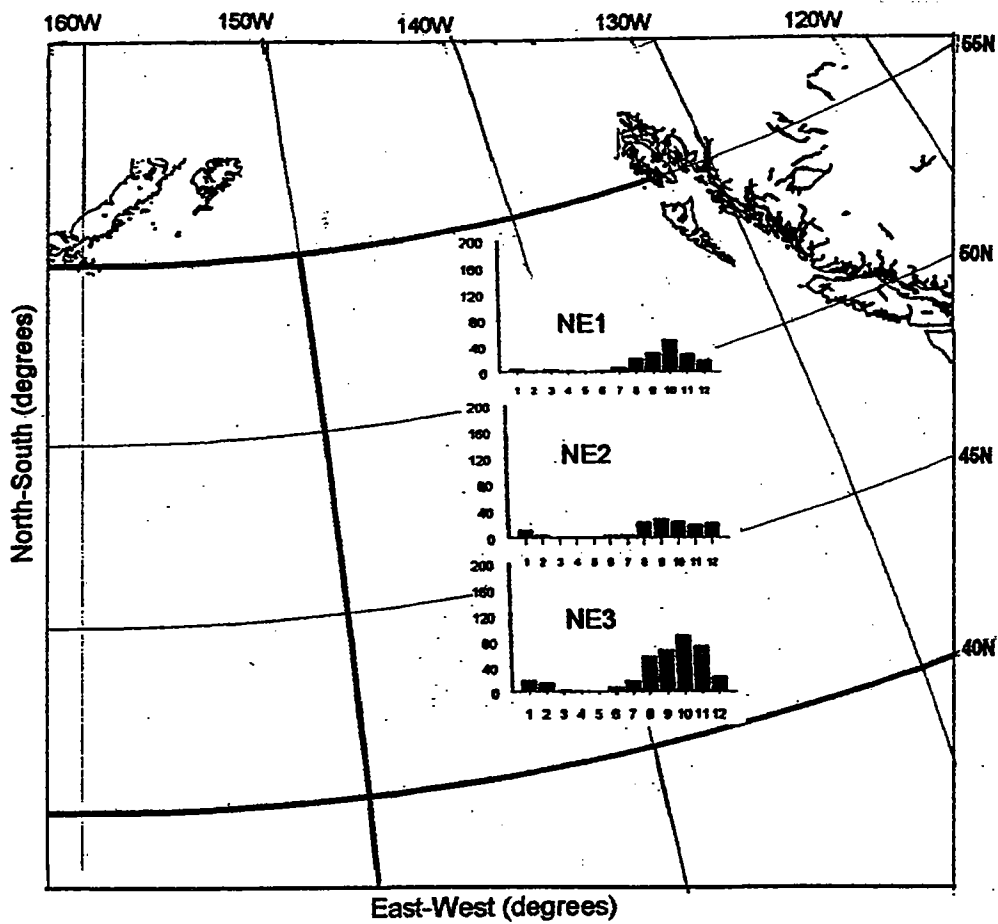




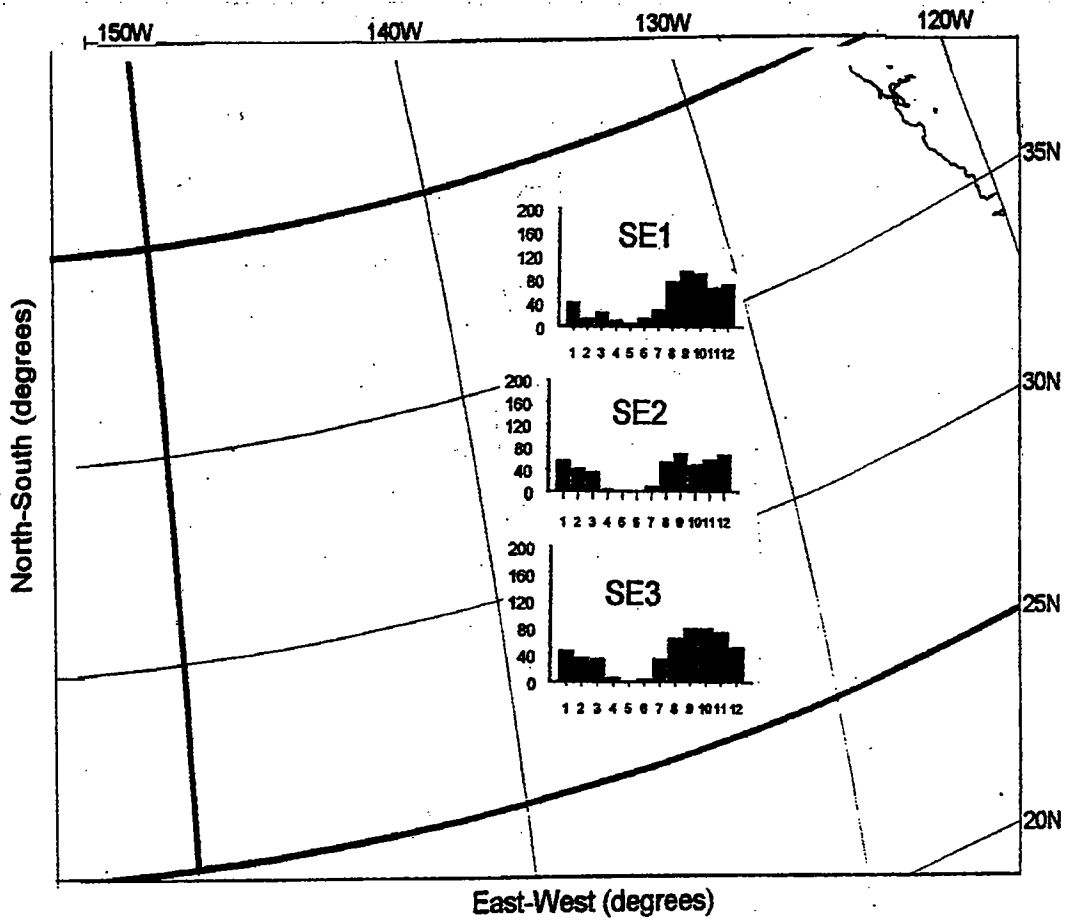
Blue whale monthly calling averages, November 1995 – September 2000



Blue whale monthly calling averages, November 1995 – September 2000

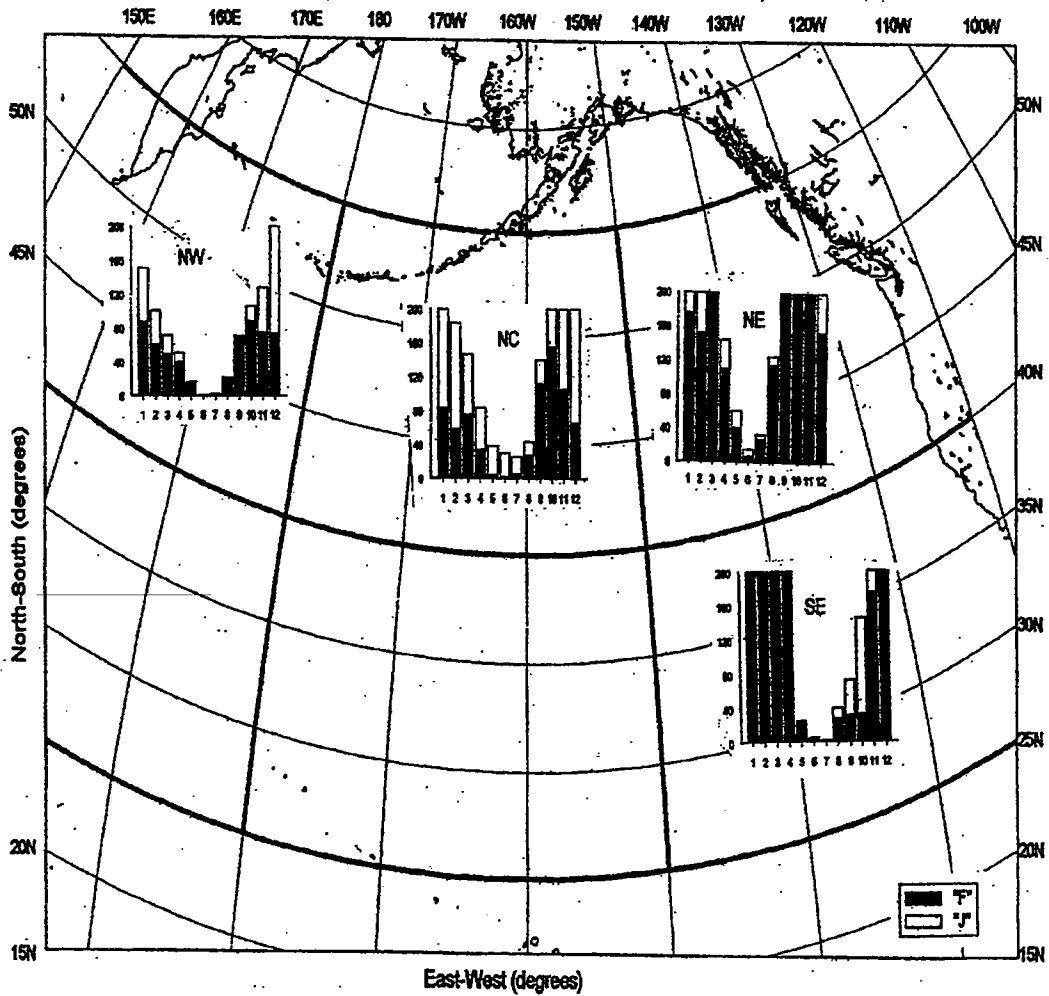


Blue whale monthly calling averages, November 1995 – September 2000

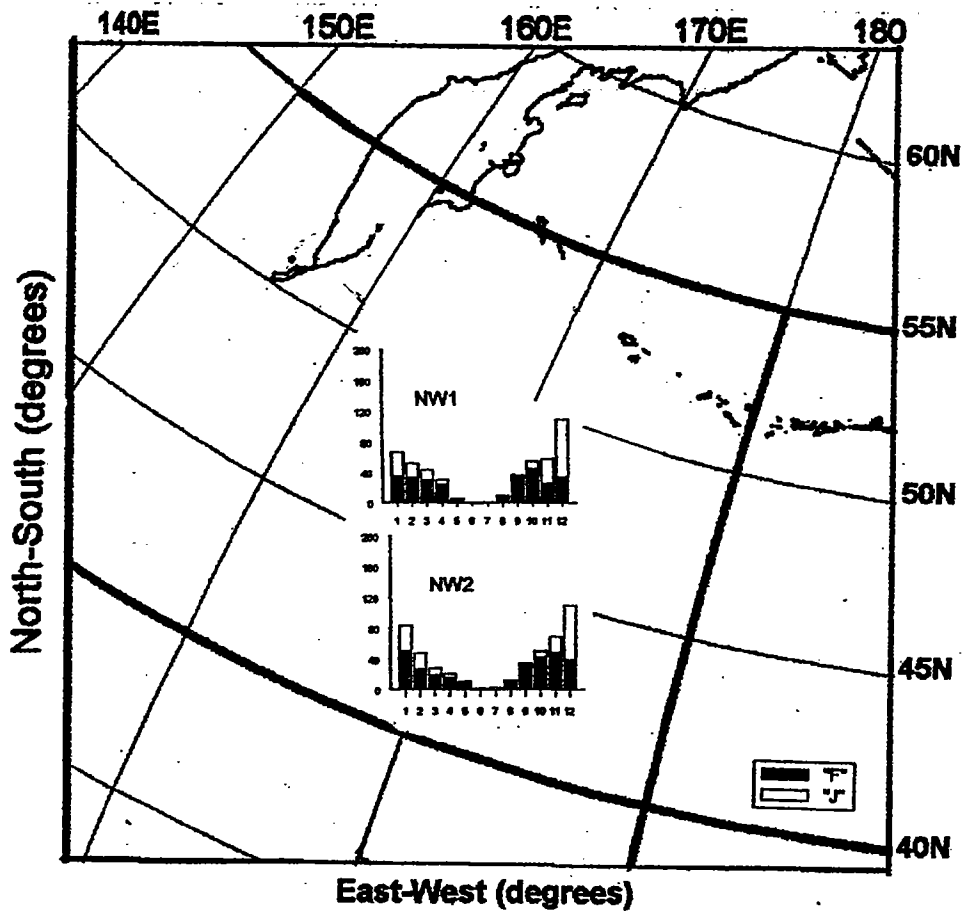


Distribution of calling whales -- page 29

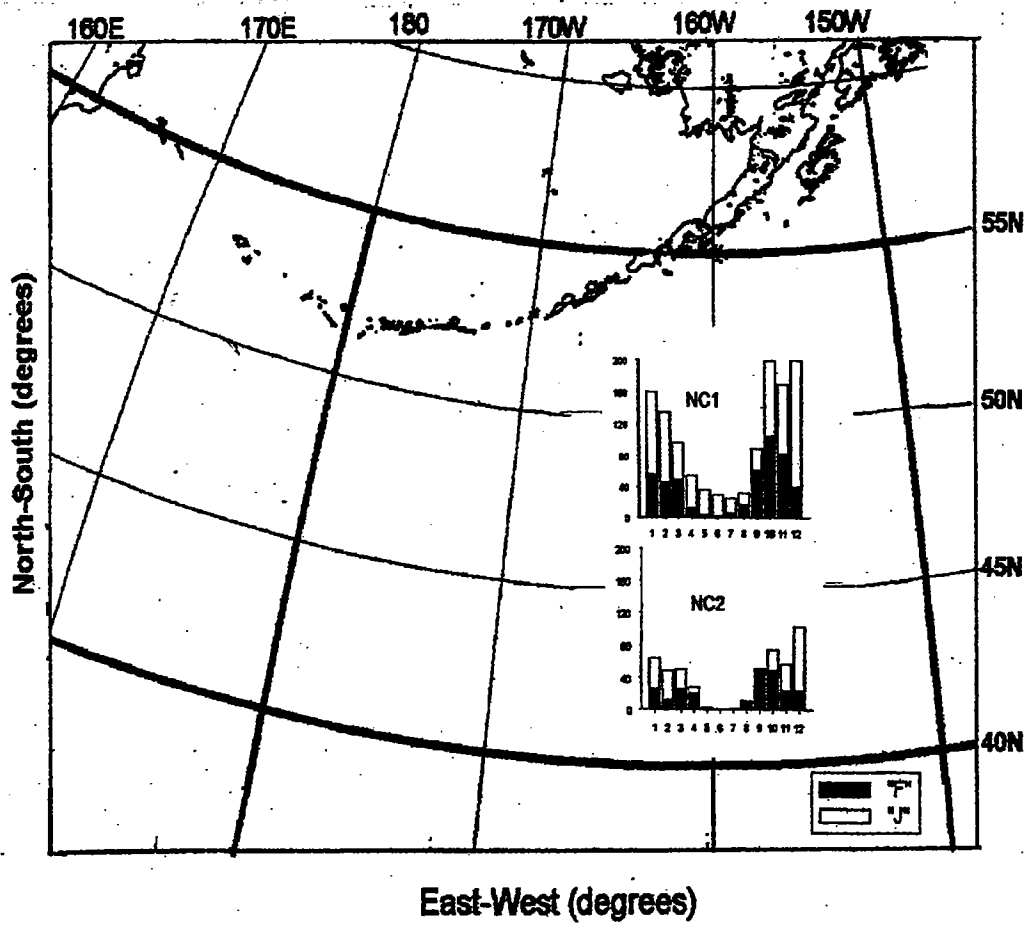
Fin whale, "F" and "J", monthly calling averages,
November 1995 – September 2000



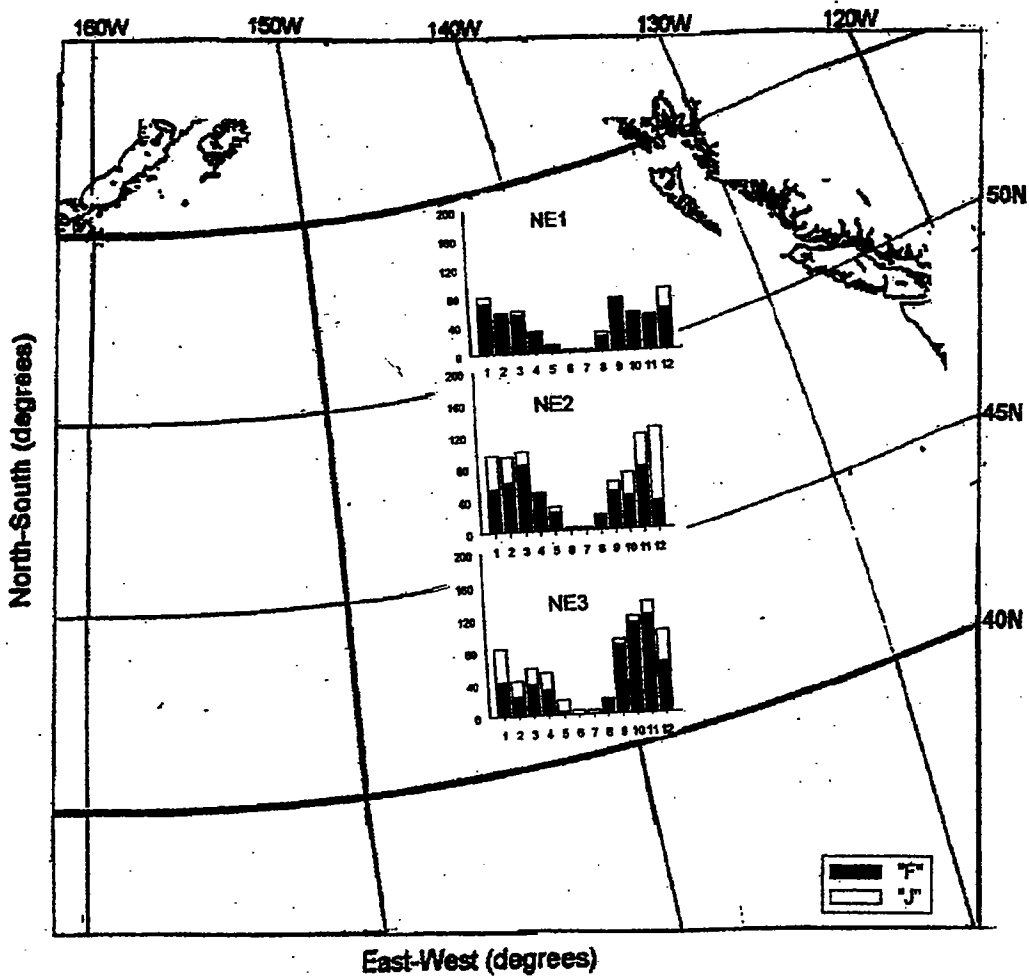
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November 1995 – September 2000



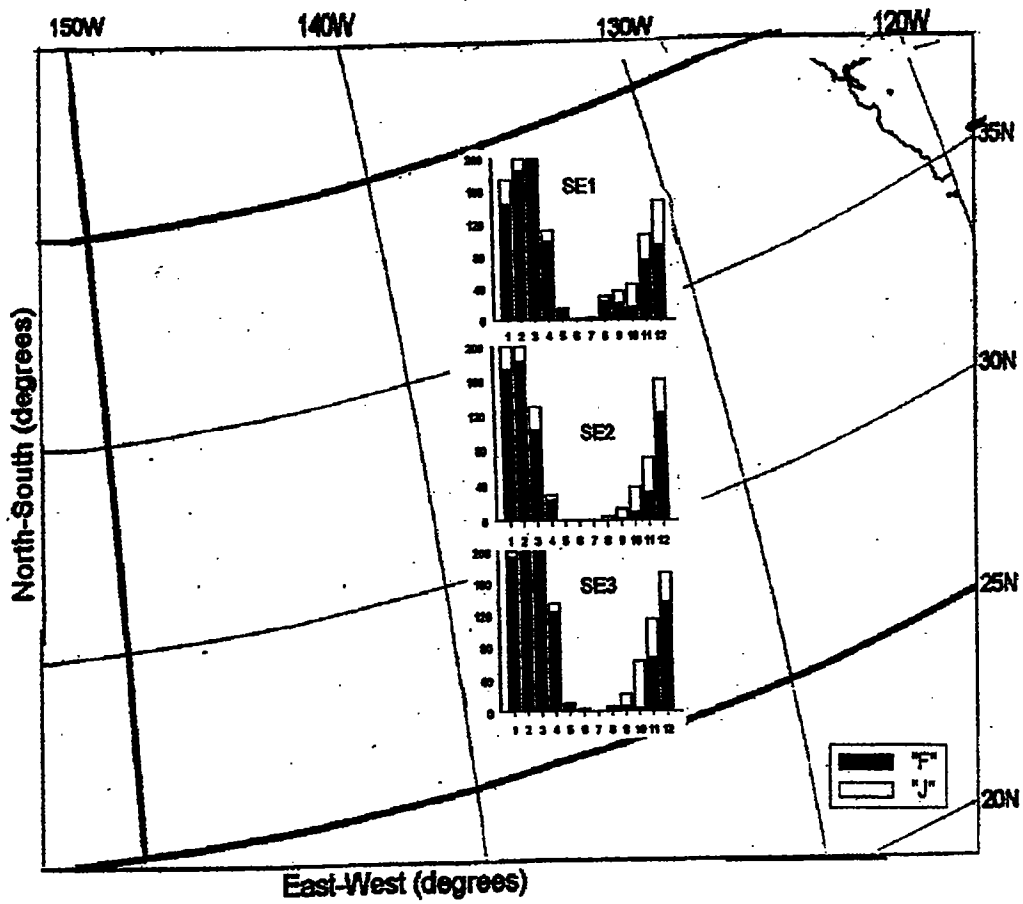
Fin whale, "F" and "J", monthly calling averages,
November 1995 – September 2000



Fin whale, "F" and "J", monthly calling averages,
November 1995 – September 2000

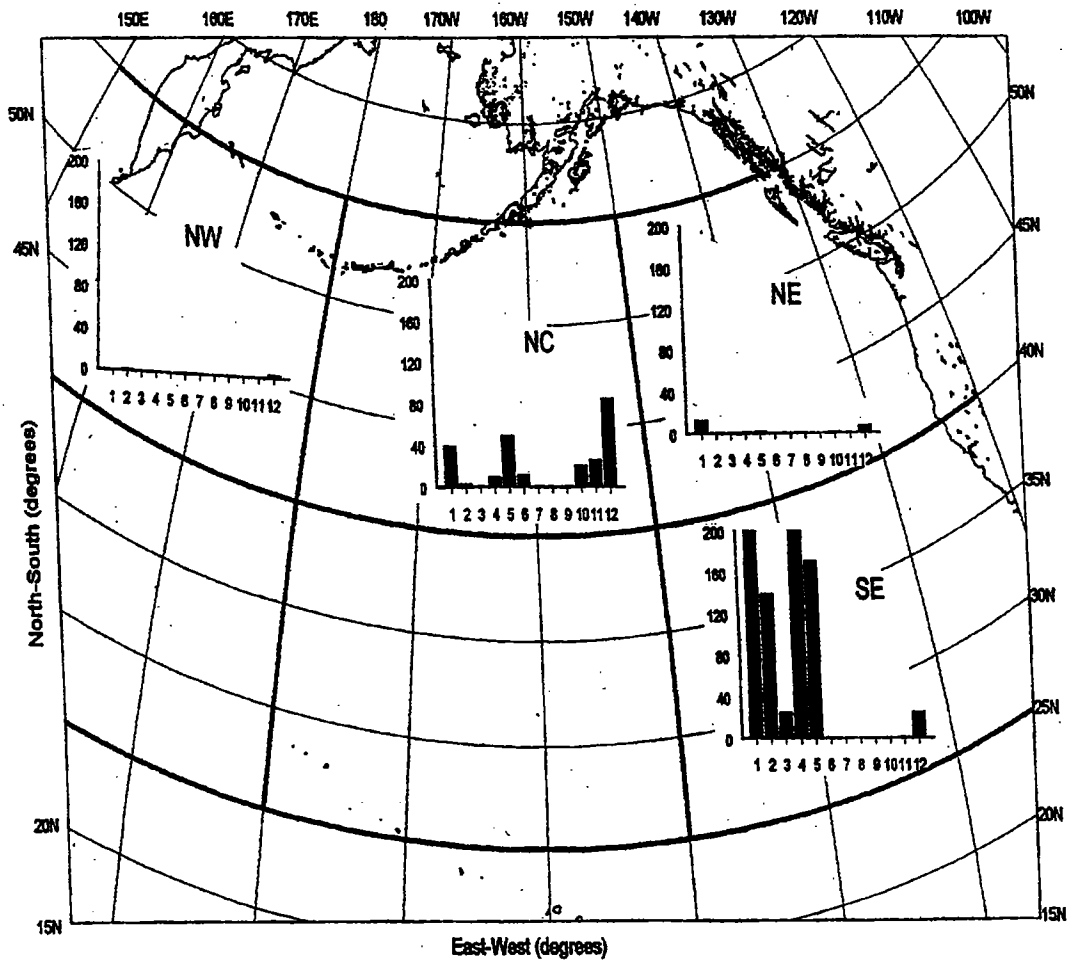


Fin whale, "F" and "J", monthly calling averages,
July 1996 – September 2000

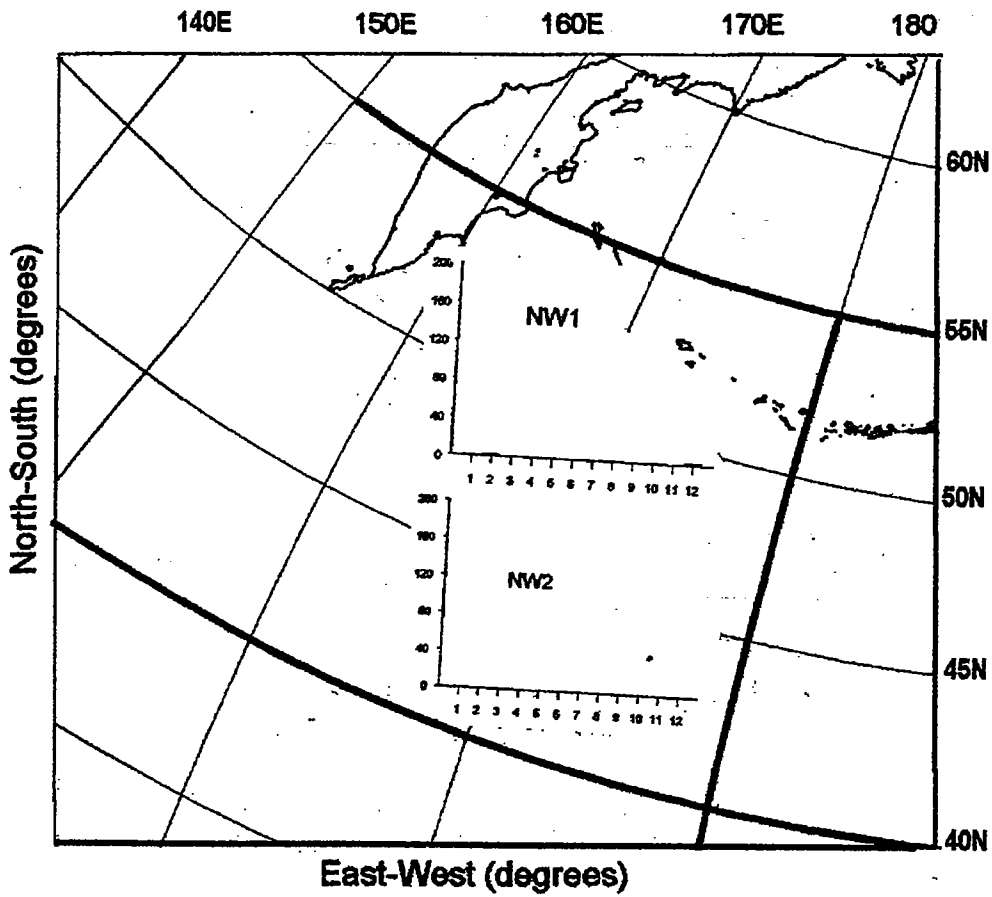


Distribution of calling whales -- page 35

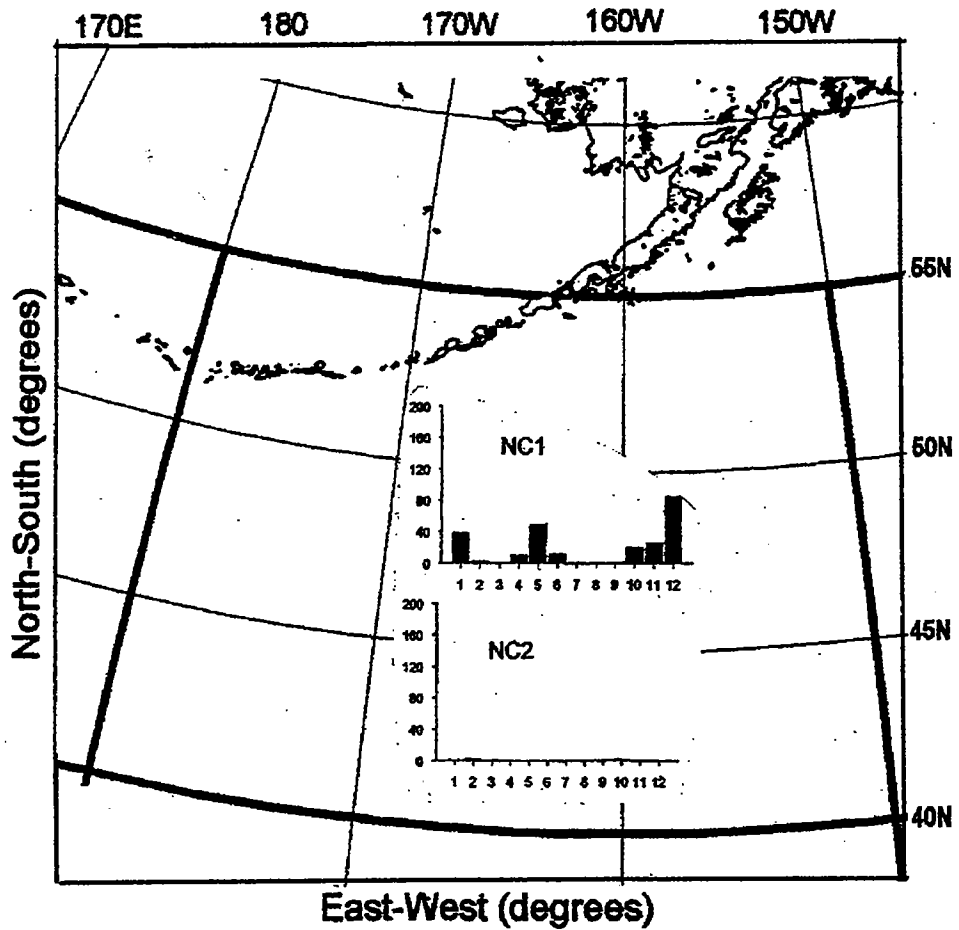
Humpback whale songs, monthly averages, 1996 - 1997



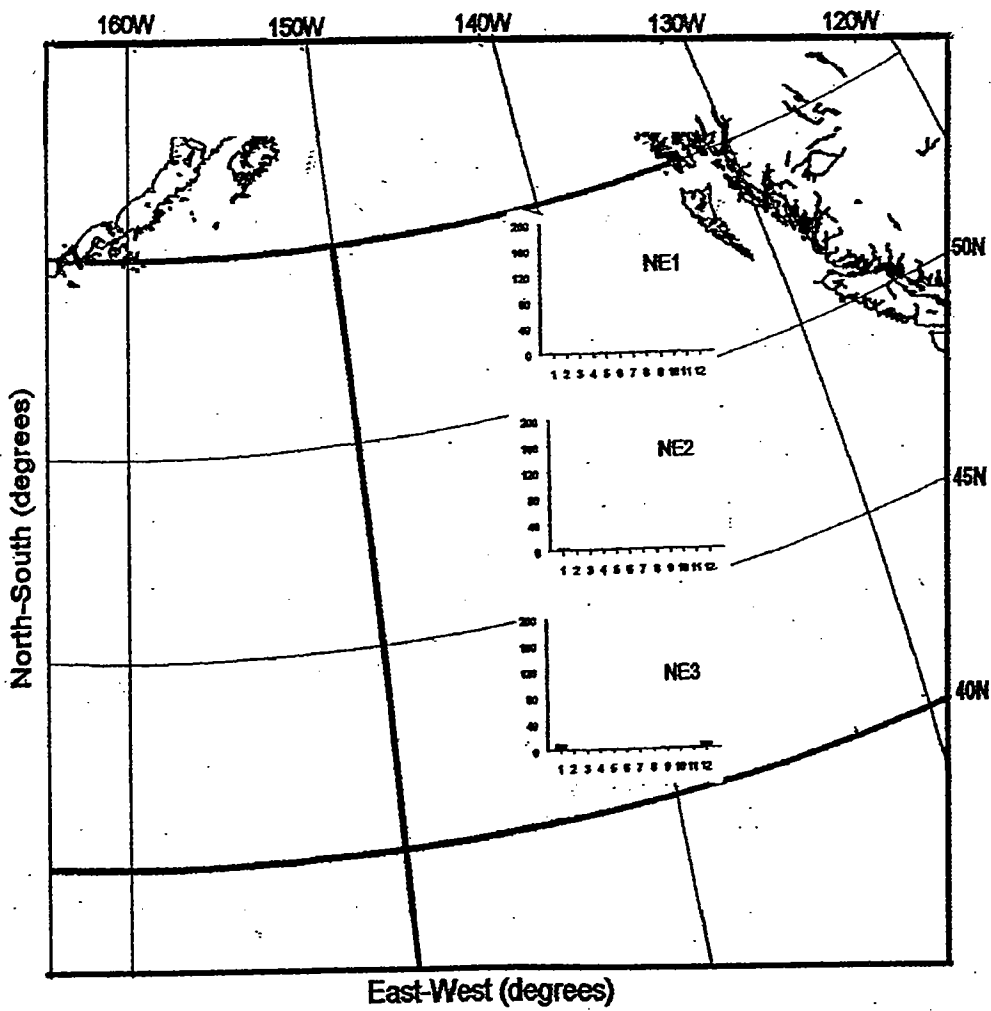
Humpback whale songs, monthly averages, 1996 - 1997



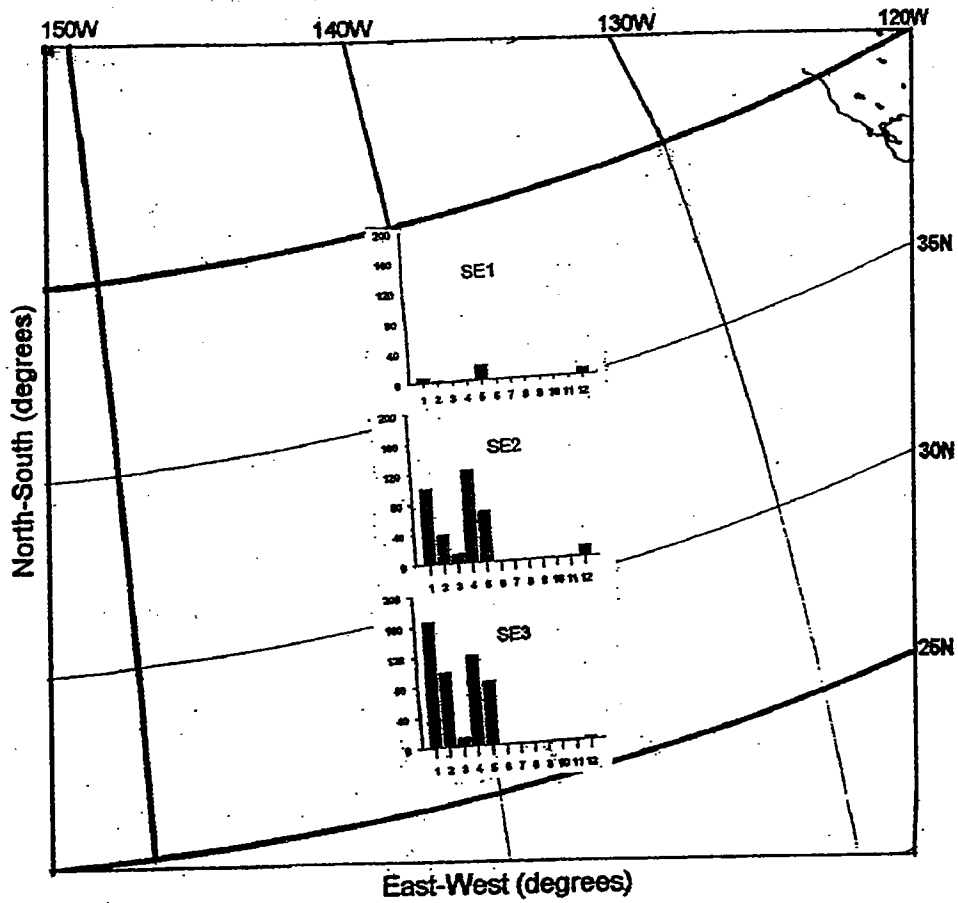
Humpback whale songs, monthly averages, 1996 – 1997



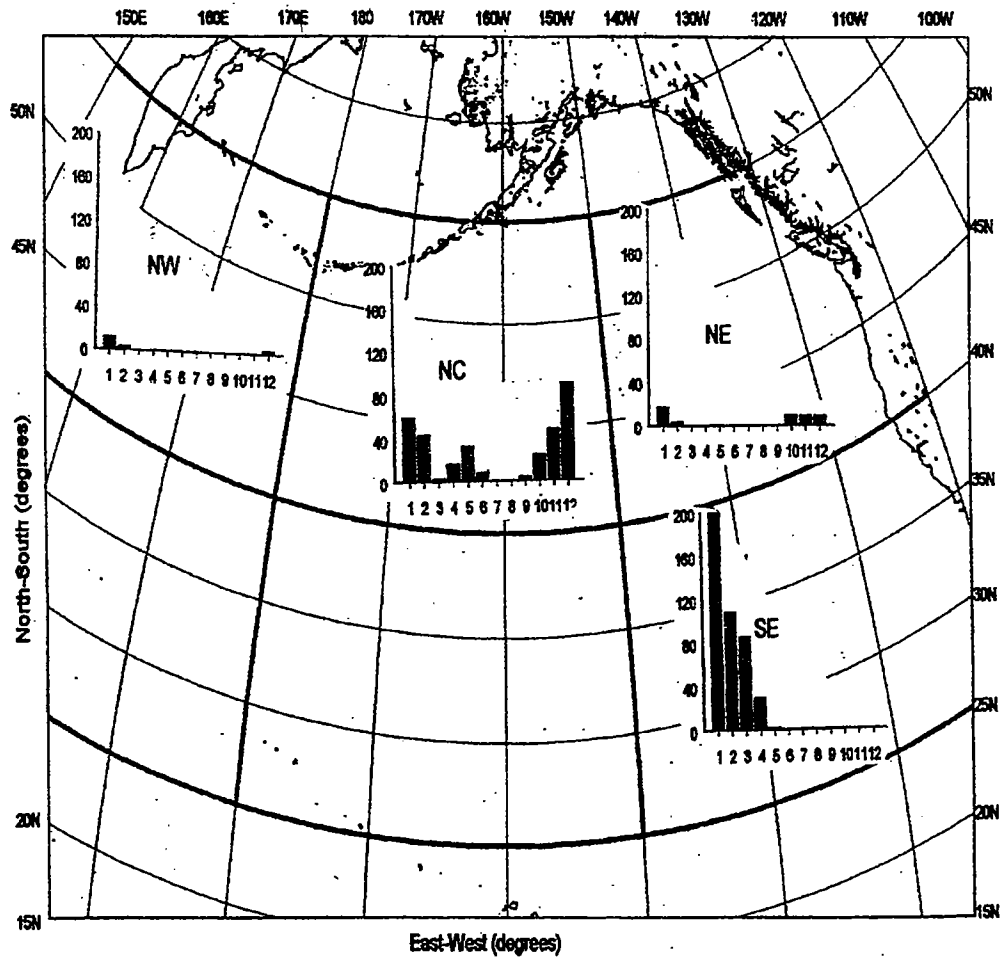
Humpback whale songs, monthly averages, 1996 - 1997

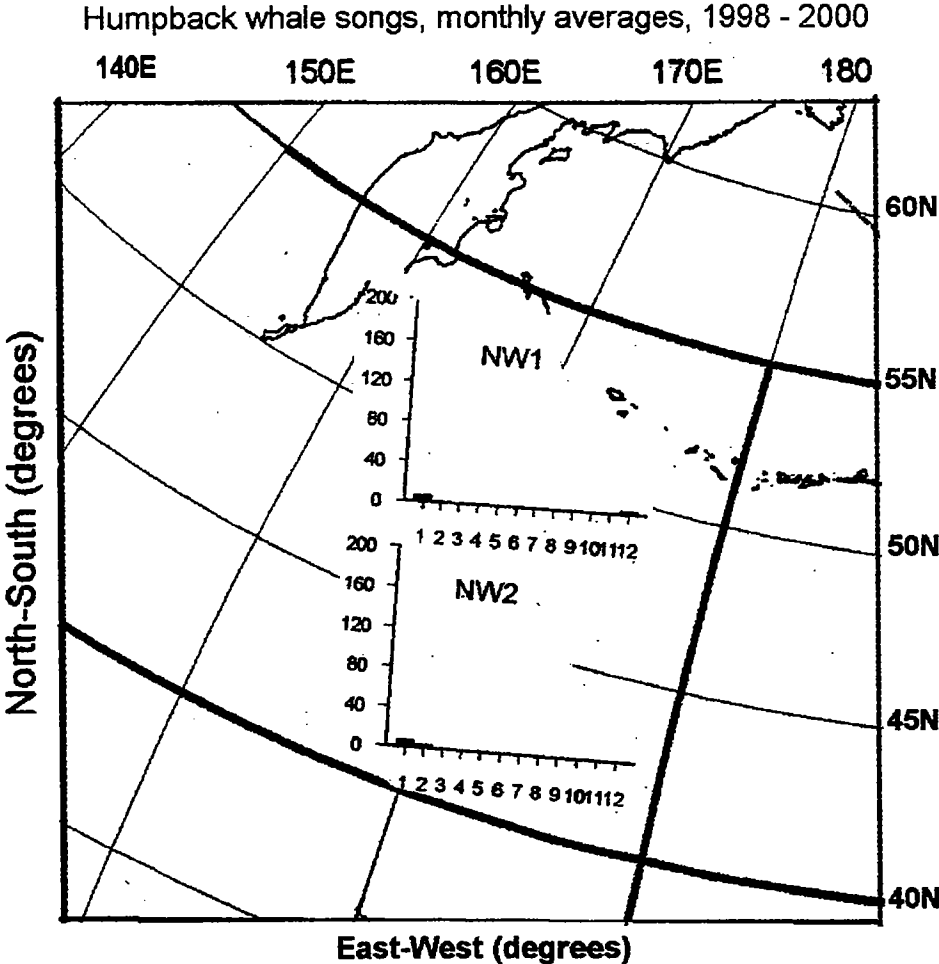


Humpback whale songs, monthly averages, 1996 - 1997

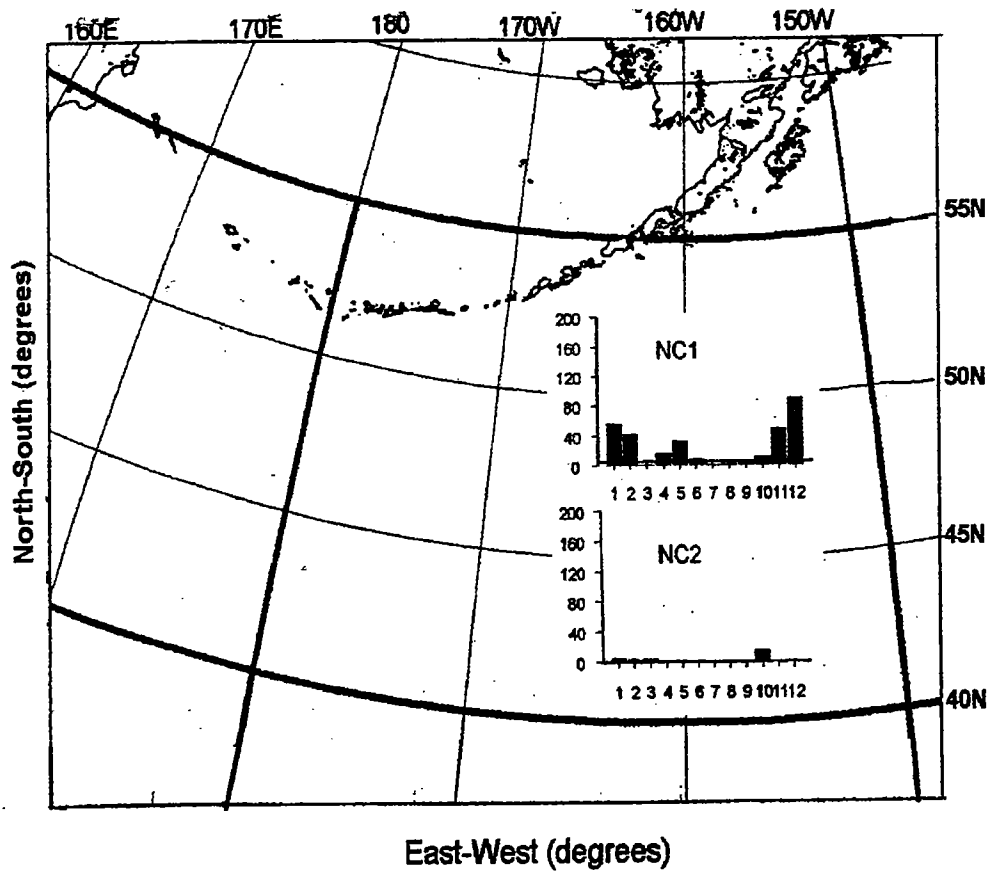


Humpback whale songs, monthly averages, 1998 – 2000

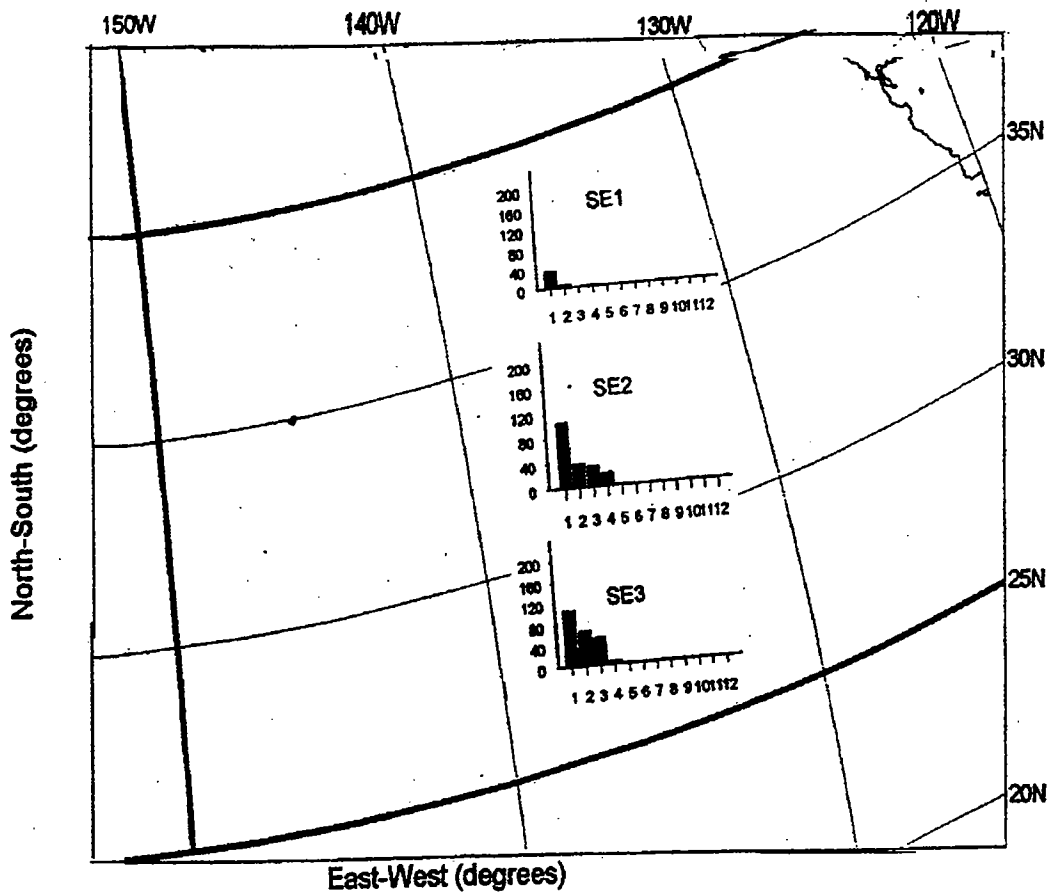




Humpback whale songs, monthly averages, 1998 – 2000



Humpback whale songs, monthly averages, 1998 – 2000



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16. Abstract (Limit: 200 words) The seasonal distribution of calling blue whales (<i>Balaenoptera musculus</i>), fin whales (<i>B. physalus</i>), and singing humpback whales (<i>Megaptera novaeangliae</i>) has been analyzed from acoustic data recorded by U.S. Navy Sound Surveillance System (SOSUS) and other hydrophone arrays in the North Pacific. The data from ten arrays were selected as representative of four Regions along the continental margins, labeled Northwest (NW), Northcentral (NC), Northeast (NE), and Southeast (SE). The call data indicate that there is a substantial population of blue whales scattered over the North Pacific and concentrated during the Fall season in the NW and NC Regions. Blue whale calls are recorded in all seasons, particularly in these NW and NC Regions. Fin whales are found in groups but also in relatively large numbers in all Regions, with most calling in the Winter season and in the NC Region, while calling is absent in most Regions during Summer. Fin whale calling includes "F" calls from individuals heard in all seasons and "J" calls from too many whales to separate, particularly prominent in the winter reproductive season. Humpback singing is recorded most in the NC and SE Regions at the time of their Winter/Spring migration. The distribution of singing humpbacks changed in both the NC and SE Regions between the 1996-1997 and 1998-2000 periods.			14.
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