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**U.S. DEPARTMENT OF COMMERCE**
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ABSTRACT

Two cruises were conducted in the eastern North Pacific Ocean to investigate the precision of large whale call locations as determined by the National Oceanic and Atmospheric Administration (NOAA) and Pacific Marine Environmental Laboratory's (PMEL) implementation of a localization and tracking routine using data from the U.S. Navy's Sound Surveillance System (SOSUS). Attempts to confirm SOSUS-derived large whale call locations by comparisons to standard vessel-based visual survey data were largely unsuccessful due to spatial and temporal differences in sampling scale. However, the deployment of an autonomous array of six bottom-moored hydrophones provided a means to evaluate SOSUS precision using passive acoustic techniques. There was good correspondence between blue whale ***(Balaenoptera*** musculus) call tracks derived from data received at the autonomous hydrophone array and at SOSUS sites. The average difference between blue whale call locations from the two systems was 4.2 + 8 .O km of latitude and 0.78 + 1.07 km longitude. In addition, simultaneous reception of fin whale calls at the autonomous array and by SOSUS provided a confirmed detection distance of - 350 km for these short pulsed signals. SOSUS is an excellent tool for detecting fin whales ***(Balaenoptera physalus)*** and for detecting and locating blue whales over broad temporal and geographic scales. However, uncertainties regarding whale calling rates and full repertoires and variability in detection distances with seasonal oceanography limits SOSUS' capabilities to provide quantitative assessments of whale abundance or habitat selection. The strength of acoustic monitoring of pelagic waters for calls produced by large whales, either by SOSUS or autonomous arrays, lies in its capability to detect whales in habitats out of reach of conventional surveys over extended spatial and temporal scales. Subsequently, these detections can augment population estimates and habitat selection indices derived by conventional means.

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## INTRODUCTION

Cetacean population estimates are usually based upon data from visual surveys conducted from ships or aircraft in neritic waters (e.g., Barlow 1995, Forney et al. 1995). Such surveys are expensive, labor intensive, and result in estimates delimited by temporal and spatial sampling constraints. Although attempts have been made to augment cetacean visual surveys with passive acoustic techniques (e.g., Watkins and Moore 1982, Thomas et al. 1986, Norris et al. 1995, Clark and Fristrup 1997), incorporation of acoustic detections in population estimation methods has been stymied by uncertainties regarding acoustic sampling range, species identification, and calling behavior.

Passive acoustic monitoring using vessel-deployed hydrophones has been successfully employed to detect and track fin whales ***(Balaenoptera physalus)*** in the North Atlantic (Watkins et al. 1984; 1987), and sperm whales ***(Physeter macrocephalus)*** in the Caribbean, offshore of the Galapagos Islands, and elsewhere (Watkins et al. 1985, Weilgart and Whitehead 1993), but researchers often do not attempt to estimate the number of calling animals. One notable exception was the augmentation of the shore-based visual census of the Bering-Chukchi-Beaufort stock of bowhead whales ***(Balaena mysticetus)*** with passive acoustic techniques (Braham et al. 1980, Johnson et al. 1981, Cummings and Holliday 1985, Clark and Ellison 1989, Clark et al. 1996). However, the successful integration of acoustic and visual data to arrive at a population estimate was accomplished only after rigorous and novel efforts on the part of the acousticians and statisticians involved in the study (Zeh et al. 1993).

In late August 1991, scientists from the Alaska Fisheries Science Center's National Marine Mammal Laboratory (NMML) entered into a collaborative pilot study with scientists at the National Oceanic and Atmospheric Administration's Pacific Marine Environmental Laboratory (PMEL) to investigate the use of the U.S. Navy's fixed hydrophone 'array system for passive acoustic detection of large whales in pelagic waters of the eastern North Pacific. PMEL scientists had previously established a direct data link from selected hydrophones on five bottom-mounted arrays of the U.S. Navy's SOSUS (Sound Surveillance System) via the

Naval Oceanographic Processing Facility (NOPF) at Whidbey Island, Washington to study low-level seafloor seismicity (Fox et al. 1994, Richelson 1998). The overall goal of the NOAA/PMEL pilot study was to evaluate the effectiveness of long-term SOSUS monitoring for determination of large whale seasonal occurrence, population estimates, and habitat assessments.

Several advantages and limitations unique to the use of SOSUS for whale detection were identified during the pilot study. Probably the greatest advantage of SOSUS is its broad geographic and temporal sampling capability relative to conventional visual techniques. However, PMEL's sampling of the SOSUS data stream is designed to detect low frequency signals, which limits its use to detection of whales that produce loud low-frequency calls, such as fin and blue whales ***(Balaenoptera musculus),*** or whales that produce distinctive calls with sufficient energy at frequencies below about 100 Hz, such as sperm whales (reviewed in Thomson and Richardson, 1995). Furthermore, during the pilot study, investigators could not estimate the precision of SOSUS-derived whale call locations, nor determine the source of signals that were not readily identifiable as whale calls. To investigate these questions, NMML/PMEL conducted cruises in the eastern North Pacific in 1994 and 1995 to 1) evaluate the precision of SOSUS-derived whale call locations, either by visual or acoustic means, and 2) to record calls in the presence of large whales to verify species identification and investigate sources of signals received by SOSUS not readily identifiable as whale calls.

Blue, fin, and sperm whales were considered 'target species' during both cruises since their calls could be detected by SOSUS and correctly classified by PMEL scientists. Blue and fin whales produce high source level calls (to 180-188 dB re 1 uPa) at roughly 20-100 Hz, suitable frequencies for detection by SOSUS. Blue whale calls are much longer than fin whale calls (19 seconds vs. 1 second; reviewed in McDonald et al. 1995), which greatly enhances SOSUS detection capability. Sperm whales produce distinctive broadband clicks (to 180 dB re 1 uPa) at rates of 1-90/seconds (Watkins et al. 1985). Although sperm whales clicks have significant energy at frequencies below 100 Hz (Goold and Jones 1995), peak energy is centered at 2-4 kHz and l0-16 kHz (Thomson and Richardson 1995); that is, frequencies above those appropriate for SOSUS detection. This document presents the results of the 1994 and 1995 cruises and compares visual detections of target species with data collected from the passive acoustic arrays.

## METHODS

A visual and acoustic survey for whales off the coasts of Oregon and Washington was conducted from 21 July to 1 August 1994 aboard the NOAA ship Suweyor. Standard line transect visual survey techniques were employed, with whale calls monitored using SOSUS and ship-deployed sonobuoys (Barlow 1988, Thomason et al. 1997).

Data obtained during the Suweyor cruise provided two important lessons: 1) "chasing" SOSUS-derived blue whale call locations to attempt visual verification was not worthwhile, and 2) another means of evaluating the precision of SOSUS-derived blue whale call locations was required. Thus in September 1995, NMML/PMEL chartered the 48 m (152 ft) supply vessel ***Auriga*** out of Seattle, Washington, to deploy an autonomous hydrophone array and to conduct a visual survey for marine mammals in a study area offshore of Oregon bounded by 45" 40'N to 46° 30'N and 128° 00'W to 130° 00'W. Lessons from the Surveyor cruise were addressed in the ***Auriga*** cruise plan as follows: 1) we restricted visual surveys to a study area bounded by SOSUS-derived blue whale call locations obtained in 1993-94 and conducted the survey in September, the period of peak reception of blue whale calls (Stafford 1995, Stafford et al. 1994); and 2) we deployed an autonomous hydrophone array prior to initiation of visual surveys, to provide an independent means of detecting and accurately tracking calling whales in the study area and by this means to calibrate SOSUS locations.

Six autonomous hydrophones were deployed near the center of the study area to track calling blue and fin whales with precision to "approximately" l-2 km (Fig. 1). The autonomous hydrophones developed by PMEL staff were originally designed to record acoustic energy from seismic sources during extended deployments in depths from 1,000 to 3,000 m. Each mooring package consisted of an anchor, acoustic release, hydrophone, recorder, and flotation device. The deployment plan called for hydrophones to be set at a depth of 700 m (the approximate depth of the sound channel axis). An undetected coiling of line during deployment caused one of the hydrophones (No. HOS) to be set at roughly 1,200 m depth; this deeper deployment did not affect the instrument's performance.

Spectrograms of blue whale call data from the six autonomous hydrophones were scrolled side-by-side on a computer screen. These data were displayed with a program written in Interactive Data Language (IDL) by programmers at PMEL on a Digital Equipment Corporation (DEC) Alpha workstation. Data from each hydrophone could be scrolled independently of the other five instruments which allowed the processor to line up calls along the screen (the times were therefore staggered). Blue whale calls were displayed on the spectrogram one at a time on the computer screen for processing ease. The geometry of the hydrophone array was such that the maximum arrival time difference for the same call on different hydrophones was 8 to 34 seconds depending on which two hydrophones are being compared (Fig. 1). A matched filter, developed from a blue whale call received on the autonomous hydrophones, was cross-correlated with all six channels and the arrival time of the peak of each cross-correlation was picked for calculation of call locations (Stafford et al. 1998: Fig. 4). The arrival times were combined with sound speed models for the eastern North Pacific (Fox et al. 1995) and compared to an initial position, determined by the computer, that represented the center of the array and then to a location that was outside the array. A least-squares fit was calculated which produced source time, latitude, and longitude of the call. Approximately 12 % (- 30 calls) of the locations were rejected, or the calls were not located due to 1) masking by earthquake noise, 2) a split between files, or 3) locations judged to be unreliable. Locations were judged as unreliable if a) they were on land or b) the standard deviations of latitude and longitude, and the Root Mean Square (RMS) errors, were very large (on the order of degrees for lat./long., > 10 for RMS value). Call locations were then plotted with a GIS package to examine their positions and relationship to bathymetry and sea surface temperature (SST). Finally a spline was fitted through the call locations to provide a smooth track of the whale's movements (Fig. 2).

## RESULTS

During the 1994 Surveyor cruise, 12 cetacean species, including sperm, fin, and humpback whales, were seen during approximately 2,775 km (1,500 nautical miles (nmi)) of visual survey (Fig. 3). Although blue whales were not seen, calls of blue, fin, and sperm whale were detected by SOSUS throughout the cruise period. Provisional plans to respond toward SOSUS-derived whale call locations proved untenable due to distances between ship and call positions. Good recordings of sperm and Baird's beaked whales ***(Berardius bairdii)*** were made using sonobuoys (Dawson et al. 1998), while only one belch-like sound could be attributed to fin whales despite 10 sonobuoy deployments during six encounters.

During the 1995 ***Auriga*** cruise, eight cetacean species were seen during roughly 2,250 km (1,215 nmi) of the visual survey (Fig. 3). As during the ***Surveyor*** cruise, sperm, fin, and humpback whales were seen, but blue whales were not. Similarly, attempts to record fin whale calls from animals under observation using sonobuoys proved largely unsuccessful. Although fin whale calls were recorded, signal amplitude and a lack of call synchrony with observed respiratory sequences suggested the animals whose calls were being recorded were out of visual range.

Both cruises were conducted in waters where blue and fin whale calls had been detected by SOSUS during 1993-94 (Fig. 4). Blue whale call detections peaked in summer and autumn, while fin whale calls were detected throughout the year. During the ***Surveyor*** cruise, emphasis was placed on attempts to visually confirm blue whale call locations provided by SOSUS. However, due to the distances involved, the vessel was diverted to an area delimited by SOSUS blue whale contacts only during the last 2.5 days of the cruise. During the ***Auriga*** cruise, emphasis was placed on deployment of the autonomous hydrophone array prior to initiation of a visual survey of a bounded study area. Only after a complete visual survey of the study area did the vessel divert to waters where blue whale calls had been detected by sosus.

Blue whale calls were detected by SOSUS 13 times during the ***Surveyor*** cruise. The first detection was on 27 July when the vessel was roughly 250 km from the call locations. Blue whale calls were detected in the same area on 28 July and again on 29 July. At 1055 Pacific Daylight Time (PDT) on 29 July, the ***Surveyor*** diverted its track and for the next 2.5 days conducted a systematic north-south search in the general area of blue whale call locations (Fig. 3, top center). However, post-cruise refinement of SOSUS-derived call locations collated with the ship's position indicates the vessel passed near two of the locations, albeit many hours later (Fig. 5). A comparison of original blue whale call locations derived from SOSUS against post-cruise refined locations resulted in differences in call positions ranging from one to three degrees longitude (Thomason et al. 1997: Fig 10). On 29 July, the ***Surveyor*** terminated surveys at 2100 PDT, roughly 11 km northeast of where a blue whale had called at 0400h. On 30 July, blue whale calls were 68 km and 122 km from the ***Surveyors'*** position at the time signals were heard. At approximately 1900 PDT that afternoon, some 8 hours after detecting the calls, the ***Surveyor*** passed within 8 km of the closest call location. On 31 July, the ***Surveyor*** passed back through the general area of blue whale calls, but at its closest point (0620 PDT) the ship was roughly 160 km from the only blue whale call localized (post-cruise) for that day.

Blue, fm, and sperm whales calls were detected both on the autonomous array and by SOSUS during the ***Auriga*** cruise. On 12 September, 257 blue whale calls were received on the autonomous hydrophone array, while 119 call locations were derived from SOSUS. From these calls, a total of 106 locations were obtained for calls occurring at the same times at both the SOSUS and the autonomous array. We are confident that the blue whale calls located by SOSUS were the same as those detected on the autonomous hydrophones based on identical frequency, temporal, and repetition characteristics. The calls consisted exclusively of "A-B" pairs, the "standard" blue whale two-part call described for the eastern North Pacific (Thompson 1965, Stafford 1995, McDonald et al. 1995, Rivers 1997). The first call (A or Type I) had a fundamental frequency of 18 + 0.2 Hz to 17 + 0.2 Hz and lasted 19.8 + 0.15 seconds. On average, the second call (B or Type II) followed 25.8 + 1.7 seconds later. The "B" call began at 18.4 + 0.2 Hz and swept down to 16.2 + 0.1 Hz over 19.5 _+ 1.4 seconds.

A plot of the combined call location data, including splined track lines for both the autonomous hydrophones (black solid line) and SOSUS (dots), indicates a single blue whale swimming southeast over about 15 hours (Fig. 2). The average spatial difference between the autonomous hydrophone and SOSUS locations for these calls was 4.2 + 8.0 km of latitude, and 0.78 + 1.07 km of longitude. While both track lines proceed in the same direction, that obtained from SOSUS does not exhibit the reversals seen in the autonomous hydrophone data. On average, calls received by SOSUS were estimated to have occurred 13.7 + 6.6 seconds later than the same call received by the autonomous array. The cause of the apparent difference in calculated source time for the same calls on both systems is unclear. Differences could be related to the U.S. Navy's beamformer, an error in the PMEL location program, or some as yet unidentified source of error. Moreover, because calls were received on only three SOSUS.arrays, there are no degrees of freedom with which to calculate location error.

Fin whales were observed 6 times (Fig. 6) and acoustically detected 26 times by SOSUS during the ***Surveyor*** cruise (Table 1). Although fin whale pulses contain significant energy at low frequencies ( - 20 Hz), these brief signals ( - 1 second) are often received at < 3 SOSUS sites which limits localization capability to approximate latitudes. Therefore, although 17 of the 26 SOSUS fin whale contacts were made on days that fin whales ***were*** seen from the ***Surveyor,*** without precise locations for the calls, it was not possible to ascertain if the fin whales observed from the ***Surveyor*** were those detected by SOSUS. Of note, the observed fin whale locations do not correspond to the time or latitudinal position of fin whale sounds detected by SOSUS (Table 1). Also, fin whale calls were not recorded during the period whales were under observation from the ***Surveyor.***

The tendency for whales at the surface to be silent corresponds with experiences reported by other researchers (e.g., McDonald et al. 1995, Watkins et al. 1987), and was reinforced when attempts to record fin whale calls using sonobuoys deployed during the six encounters resulted in reception of only one belch-like signal. Fin whale calls were detected on at least one of the autonomous hydrophones nearly everyday during the ***Auriga*** cruise, but often location could not be determined because call reception was limited to one or two hydrophones. Although fm whale pulses are often difficult to localize, signal reception was adequate to determine locations for fin whale calls on 4 days: 9, 12, 13 and 15 September 1995 (Fig. 7). One particularly distinct call series, detected on both the autonomous and SOSUS arrays on 13 September, provided a confirmed SOSUS-detection distance of approximately 350 km for these distinctive pulse-like calls. We believe these to be the same calls based on consistent temporal and frequency patterns depicted in spectrograms derived from each system. Fin whale calls were also located on 15 September, a day when fin whales were seen; however, these calls occurred 8 hours before visual contact. Calls were detected on the autonomous arrays during a 2-hour fin whale observation period that day, but could not be localized and therefore could not be attributed to the animals sighted. As during the 1994 field effort, attempts to record calls from fin whales under observation during the ***Auriga*** cruise were largely unsuccessful.

Sperm whales were seen 12 times (Fig. 8), and were detected by SOSUS each day of the ***Surveyor*** cruise, sometimes all day long (Table 2). However, as with fin whale pulses, the short duration (< 1 second) of sperm whale clicks limits the capability of SOSUS to determine their position. During the ***Auriga*** cruise, sperm whales were seen six times on li September (Fig. 9). Although sperm whale clicks were received by SOSUS, the autonomous hydrophones, and sonobuoys, it was not possible to correlate the signals. Given that sperm whale clicks are generally detected over a l0-15 km range (e.g., Watkins and Moore 1982), it is unlikely that whales detected by SOSUS were the same as those detected by the autonomous hydrophones or sonobuoys.

## DISCUSSION

The 1994 and 1995 NMML/PMEL field experiments provided an opportunity to compare three types of detection methods for large whales in the North Pacific: two acoustic and one visual. All three target species were detected within the study area during the ***Surveyor*** and ***Auriga*** cruises; sperm and fin whales by visual and acoustic means, and blue whales by acoustic means only. Attempts to "ground-truth" SOSUS via visual techniques were largely unsuccessful. Blue whale call locations provided by SOSUS proved too far away for the vessel to approach in a reasonable period; that is, the temporal and spatial scale of SOSUS and vessel-based visual sampling could not be brought into correspondence. Overall, temporal correspondence of fin and sperm whale sightings with SOSUS detections was also poor. The ability to detect, but not localize, fin and sperm whale calls using SOSUS confounds detailed comparisons.

The foremost result of the experiments was achieved by comparing blue whale tracks determined from call reception at the autonomous hydrophone array and from SOSUS. The SOSUS locations resolved for the blue whale calling on 12 September 1995, while less accurate than those from the autonomous hydrophones, displayed the same temporal variation and overall movement patterns (see Fig. 2). When viewed on a broad scale, SOSUS locations for blue whale calls matched those provided by the autonomous hydrophones quite well (Fig. 10). Similarly, although unable to routinely determine fin whale call locations, results of the acoustic "ground truth" of SOSUS suggests that fin whales can be detected at least to 350 km from a SOSUS site; likely at greater distances during periods of ideal signal transmission (i.e., low ambient noise). Based on these results, Moore et al. (1998) describe seasonal fin whale occurrence for five areas in the North Pacific from SOSUS data analyzed during the pilot study.

Problems relating to interpretation of SOSUS data remain. Although NMML and PMEL maintain libraries of SOSUS recordings from the North Pacific, we are uncertain what call detections mean in terms of the number (and sometimes species) of animals present at the time of the recording. Fin whale data obtained during the field experiments provides a good example of this dilemma: while SOSUS received many fin whale calls during both cruise periods, fin whales observed from the vessels were largely silent as determined by sonobuoy deployments. Silent whales are undetected whales, using SOSUS. For SOSUS data to support quantitative assessments of whale abundance and habitat selection requires better information on whale repertoires and calling behavior than is currently available. Furthermore, although blue, fin, and sperm whales are the most readily detected by SOSUS, other species frequenting the North Pacific produce calls that may also be detected. Specifically, northern right ***(Eubalaena glacialis),*** gray ***(Eschrichtius robustus),*** humpback ***(Megaptera novaeangliae),*** minke ***(Balaenoptera acutorostrata),*** and Bryde's whales ***(Balaenoptera edeni)*** all produce calls at frequencies from < 100 Hz, although the full call repertoires for most species are probably not yet described (Thomson and Richardson 1995).

For now, the precision of SOSUS seems best suited for depicting the seasonal occurrence and broad scale distribution of blue and fin whales. While patterns of call reception can not yet be applied to quantitative assessments, real-time monitoring of pelagic waters can provide information important to the interpretation of population estimates obtained by conventional means. For example, if blue whales are located by SOSUS in pelagic waters outside the boundaries of a study area during standard aerial or vessel surveys, there is tangible evidence that the population is larger than that estimated by conventional techniques. Perhaps more importantly, patterns of cetacean distribution can be investigated over broad spatial and temporal scales. Subsequently, basin-wide distribution of large whales and oceanographic features can be investigated (e.g., Moore et al. 1998) and monitored over time.

In the long term, the integration of acoustic monitoring with visual survey techniques should lead to the development of an acoustic corollary to the detection function. A detection function (g[y]) is derived to account for whales that go undetected during visual surveys' (Buckland et al. 1993) and is defined as the probability of detecting an animal, given that it is at distance "y" from a random line or point. Calculation of a detection function is fundamental to the estimation of cetacean abundance from visual survey data. While the integration of passive acoustic methods to surveys of large whales is still in its infancy, the development of an acoustic detection function will be required to make the leap to quantification. In the case of passive acoustic monitoring, the detection function must incorporate distance, behavioral factors, and transmission loss characteristics of the water column. For example, an acoustic detection function (g[y]a) would be the probability of detecting a whale call, given that it is at distance "y" from a receiver, ***and*** given the likelihood that 1) the individual will call and that 2) the call will be received at the hydrophone given ambient acoustic conditions. This statistic will vary with the call characteristics of each species, similar to the variance in visual detection functions with animal size, propensity to group, and species-specific dive profiles. Refinement of detection distances and localization capabilities from SOSUS will require additional acoustic "ground truth" investigations, such as the prototype developed during the ***Auriga*** cruise.

Allocation of sampling effort during visual surveys remains an important consideration to proper visual survey design (e.g., Benson et al. 1995). The refinement of passive acoustic techniques for estimation of whale population parameters will require the same rigor, coupled with selection or development of appropriate transmission loss models. Because large whales spend so much time underwater and out of view and rely on the acoustic modality for much of their behavioral ecology, we suggest that development of these techniques for population monitoring will be well worth the effort.

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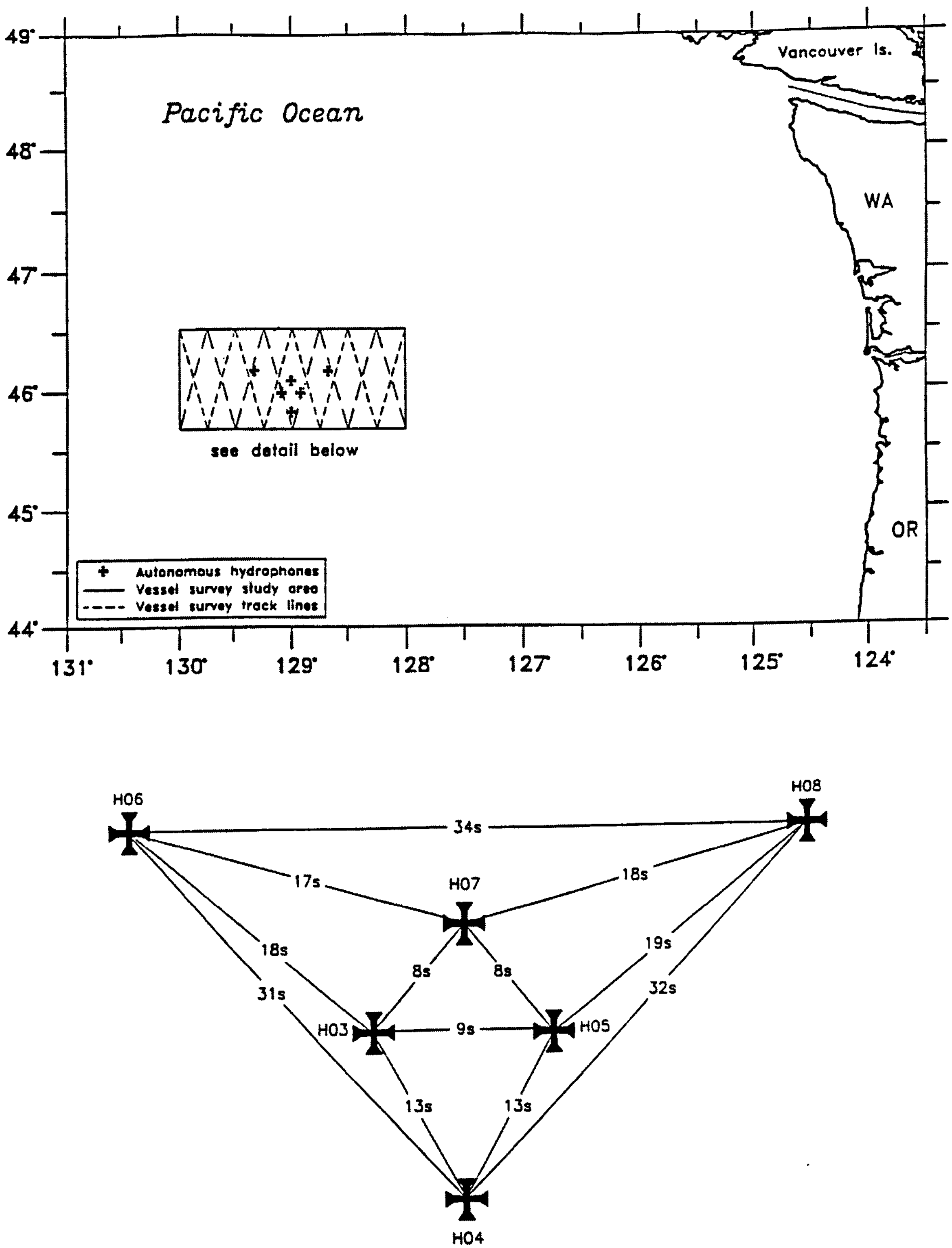



Figure l.--1995 Auriga cruise study area depicting locations of six autonomous hydrophones and visual survey track lines(top) and autonomous array geometry and example blue whale call arrival at each of the six hydrophones (bottom).

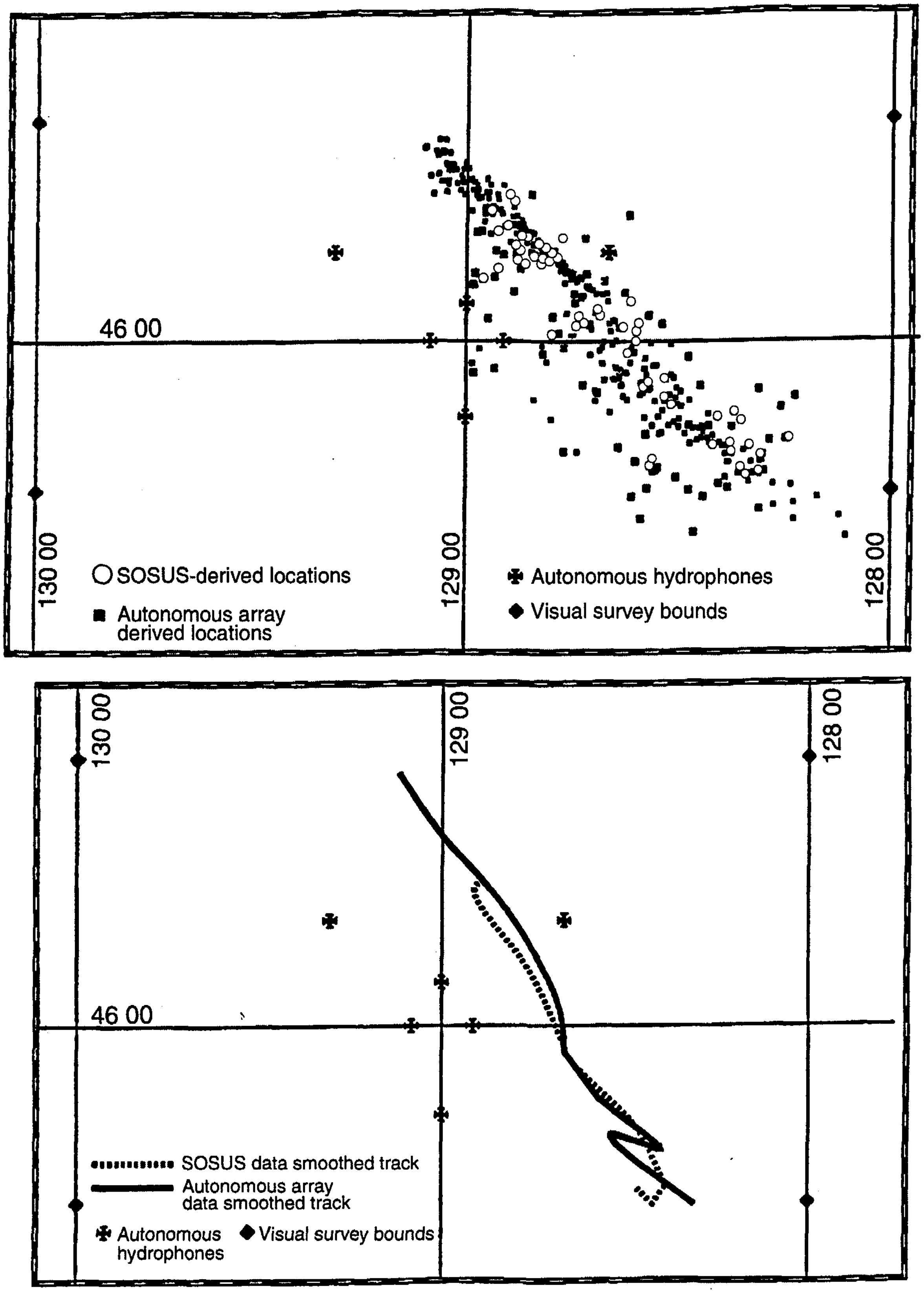



Figure 2.--Combined blue whale locations and call tracks from the autonomous array and SOSUS during the Auriga cruise.

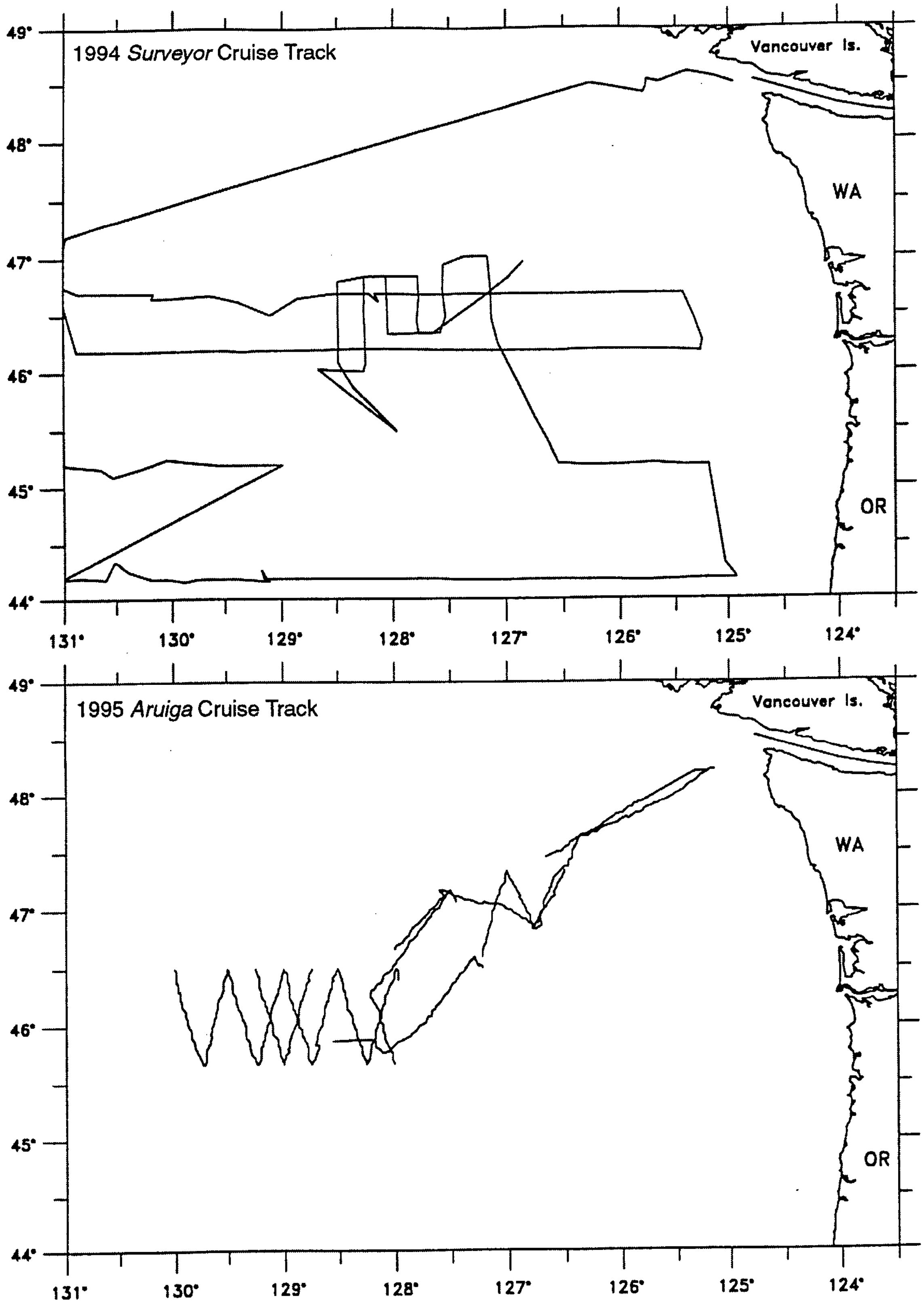
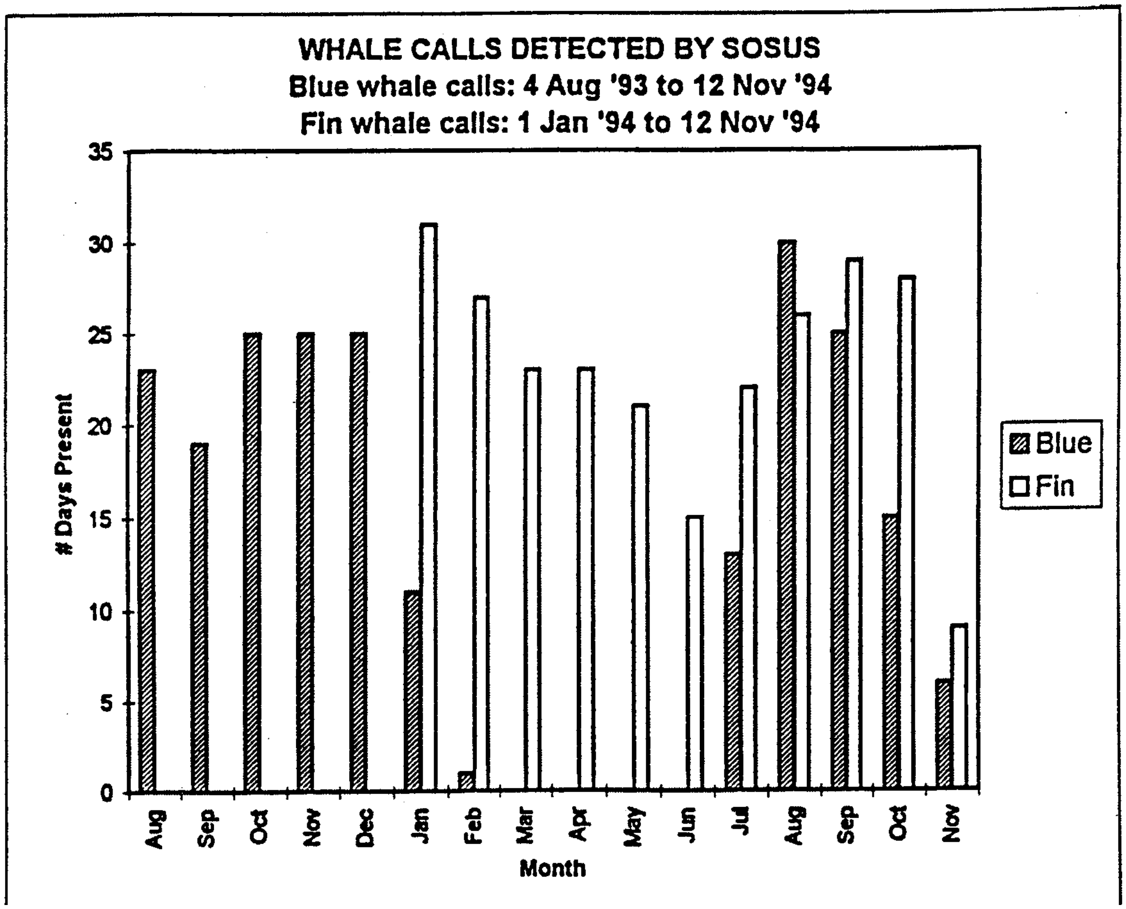



Figure 3.--Survey tracks for the 1994 NOAA ship Surveyor and 1995 ***Auriga*** cruises.

| Month | Blue | Fin |
|---|---|---|
| Aug | 23 | |
| Sep | 19 | |
| Oct | 25 | |
| Nov | 25 | |
| Dec | 25 | |
| Jan | 11 | 31 |
| Feb | 1 | 27 |
| Mar | 0 | 23 |
| Apr | 0 | 23 |
| May | 0 | 21 |
| Jun | 0 | 15 |
| Jul | 13 | 22 |
| Aug | 30 | 26 |
| Sep | 25 | 29 |
| Oct | 15 | 28 |
| Nov | 6 | 9 |




Figm 4.--Number of days per month that blue and fin whale calls were detected via SOSUS offshore Washington/Oregon, 1993-94.

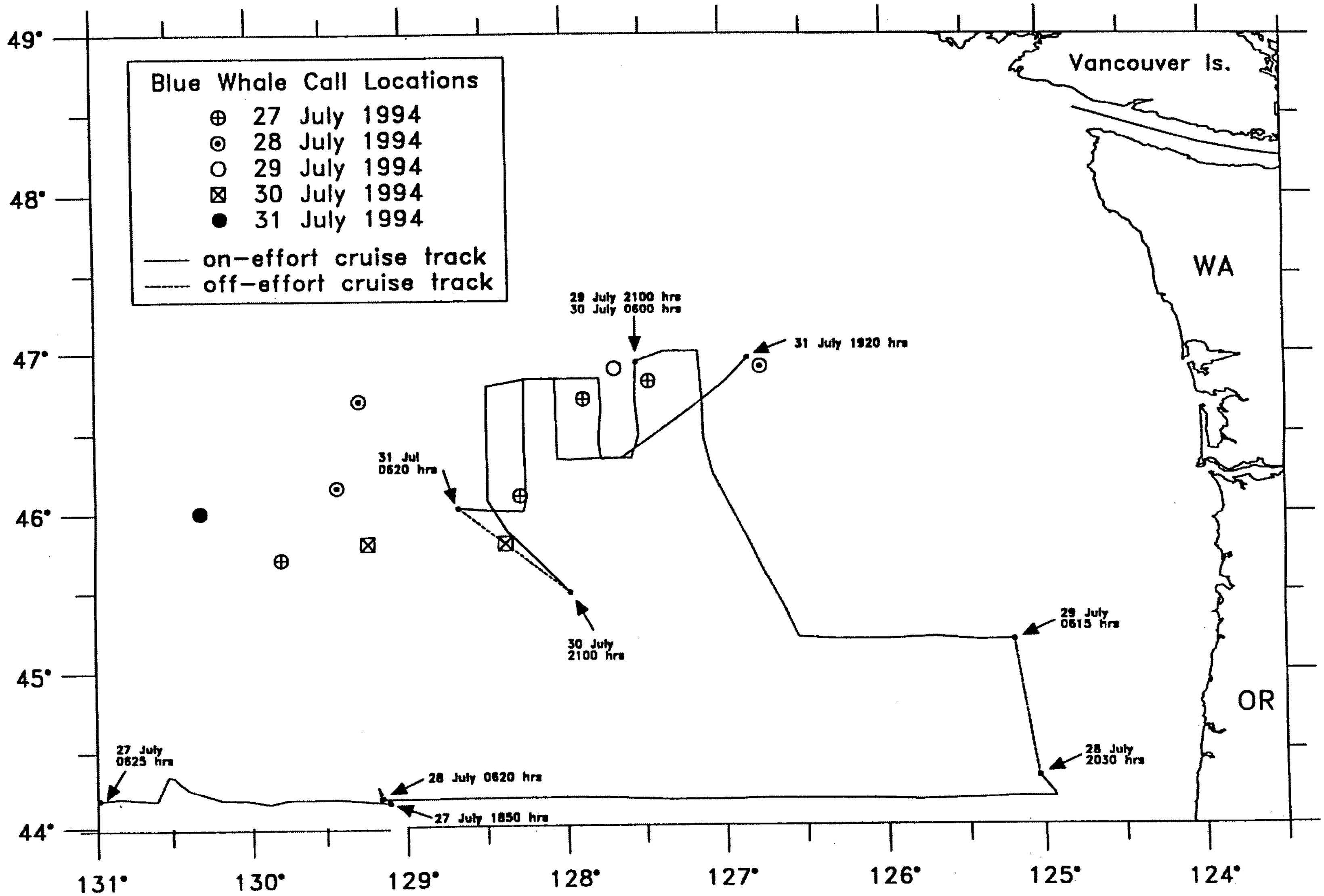



Figure 5.--Refined SOSUS-derived blue whale call locations and trackline of the NOAA ship Surveyor Cruise, 27-3 1 July 1994.

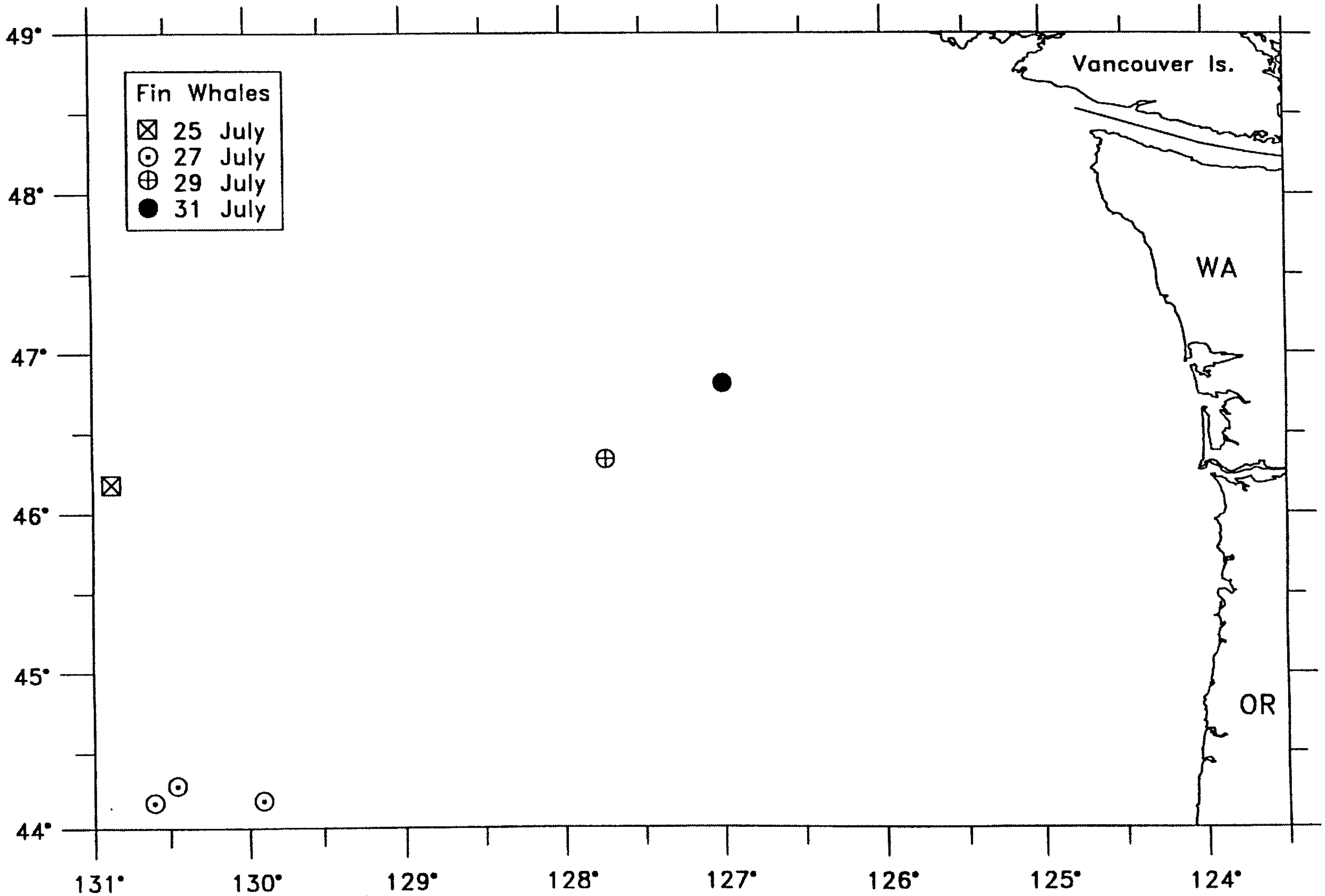



Figure 6.--Location of six fin whale sightings during the 1994 *Surveyor* cruise.

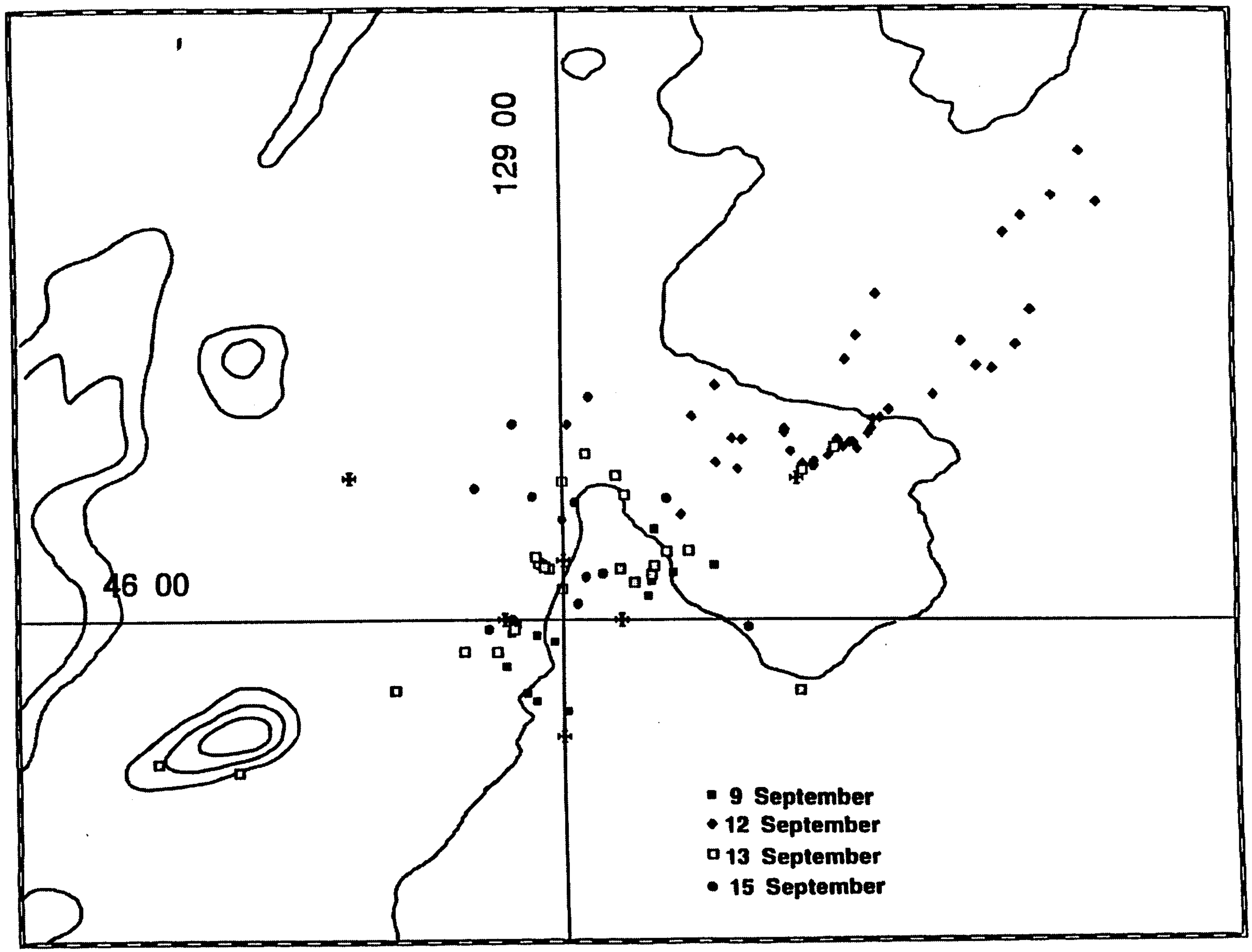



Figure 7.--Fin whale call locations determined by autonomous hydrophones on 9, 12, 13, and 15 September 1995.

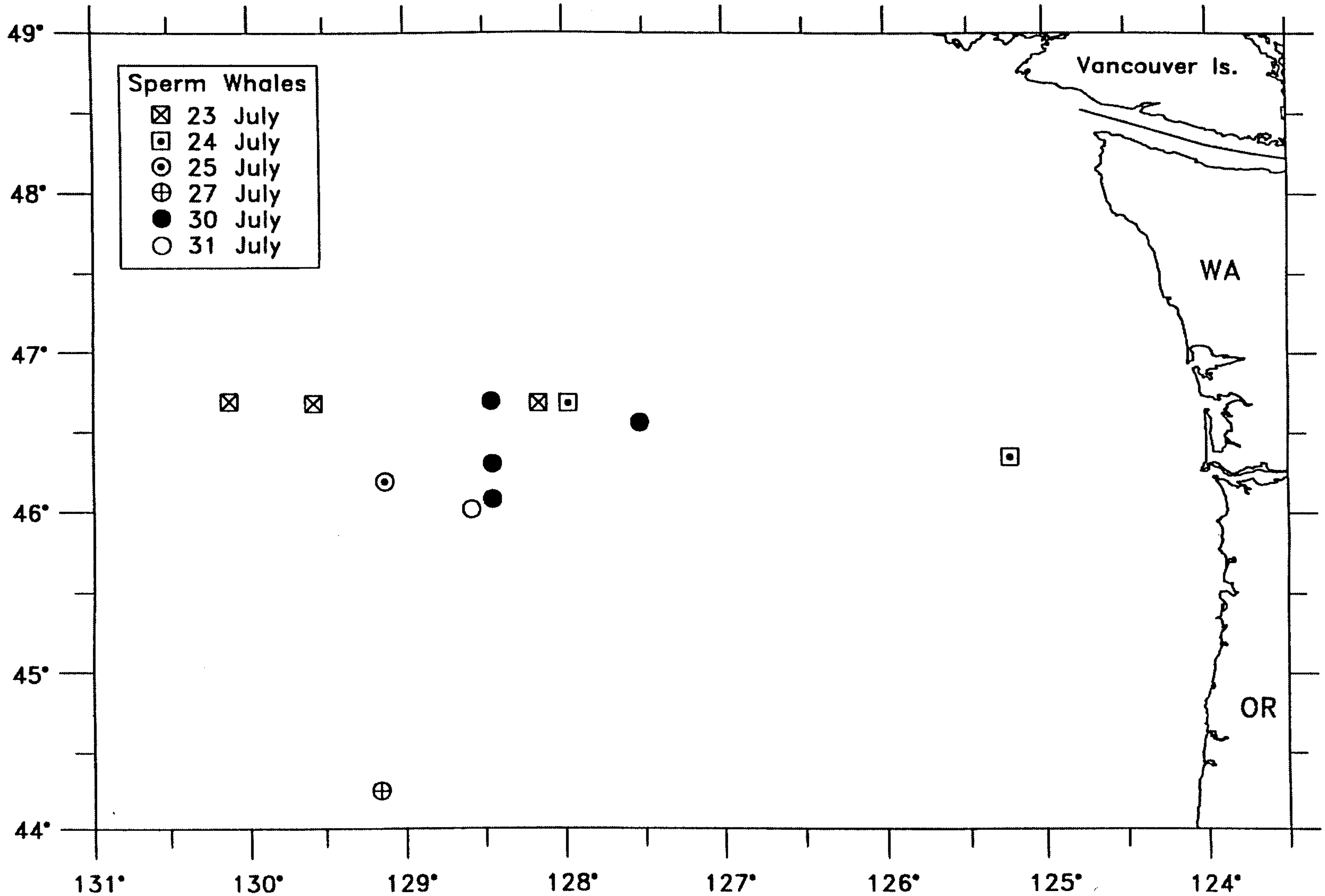



Figure 8.--Location of 12 sperm whale sightings during the 1994 NOAA ship *Surveyor* cruise.

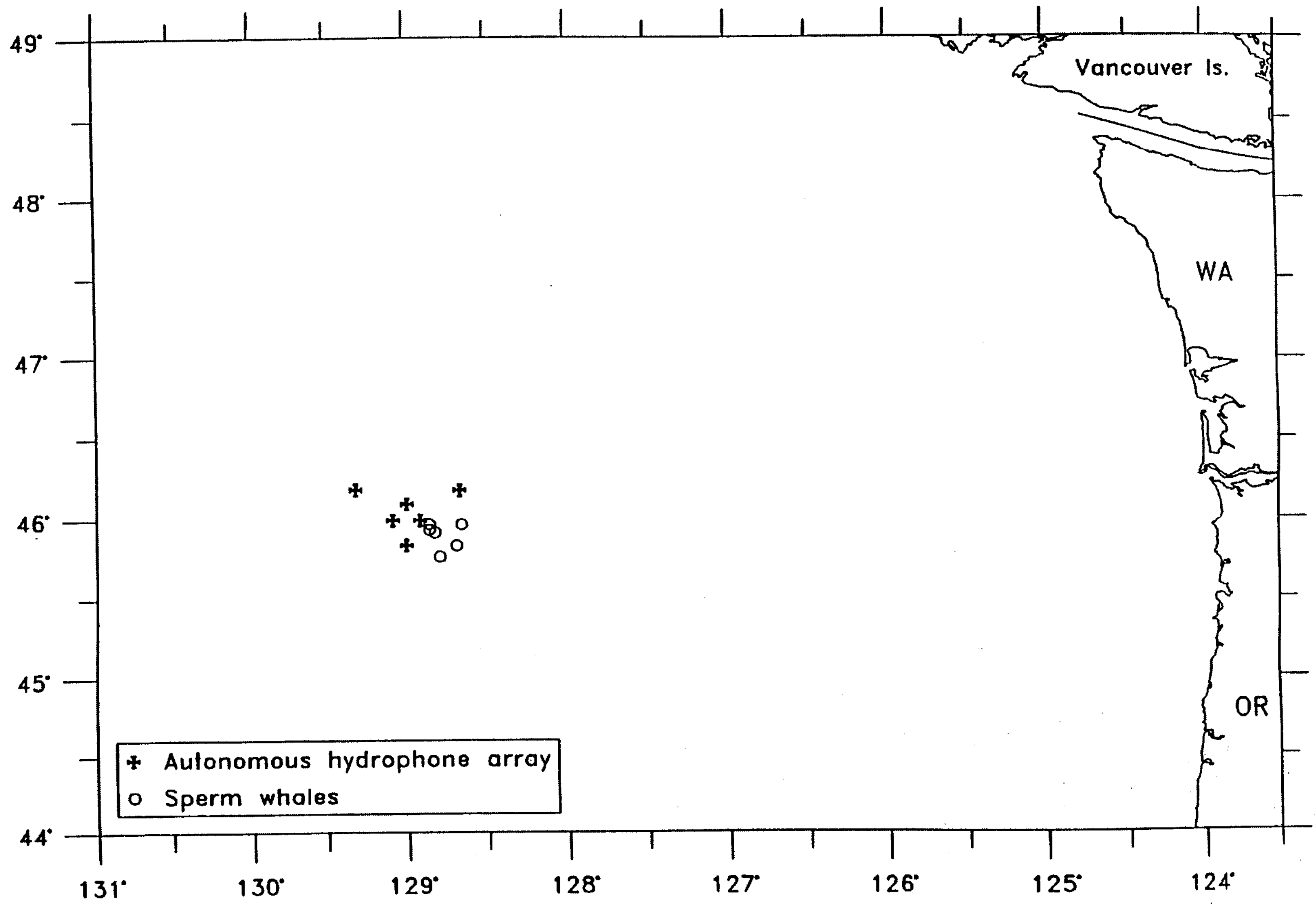



Figure 9.--Distribution of six sperm whale sightings on 11 September 1995, relative to the location of the autonomous hydrophone array deployed during the *Auriga* cruise.

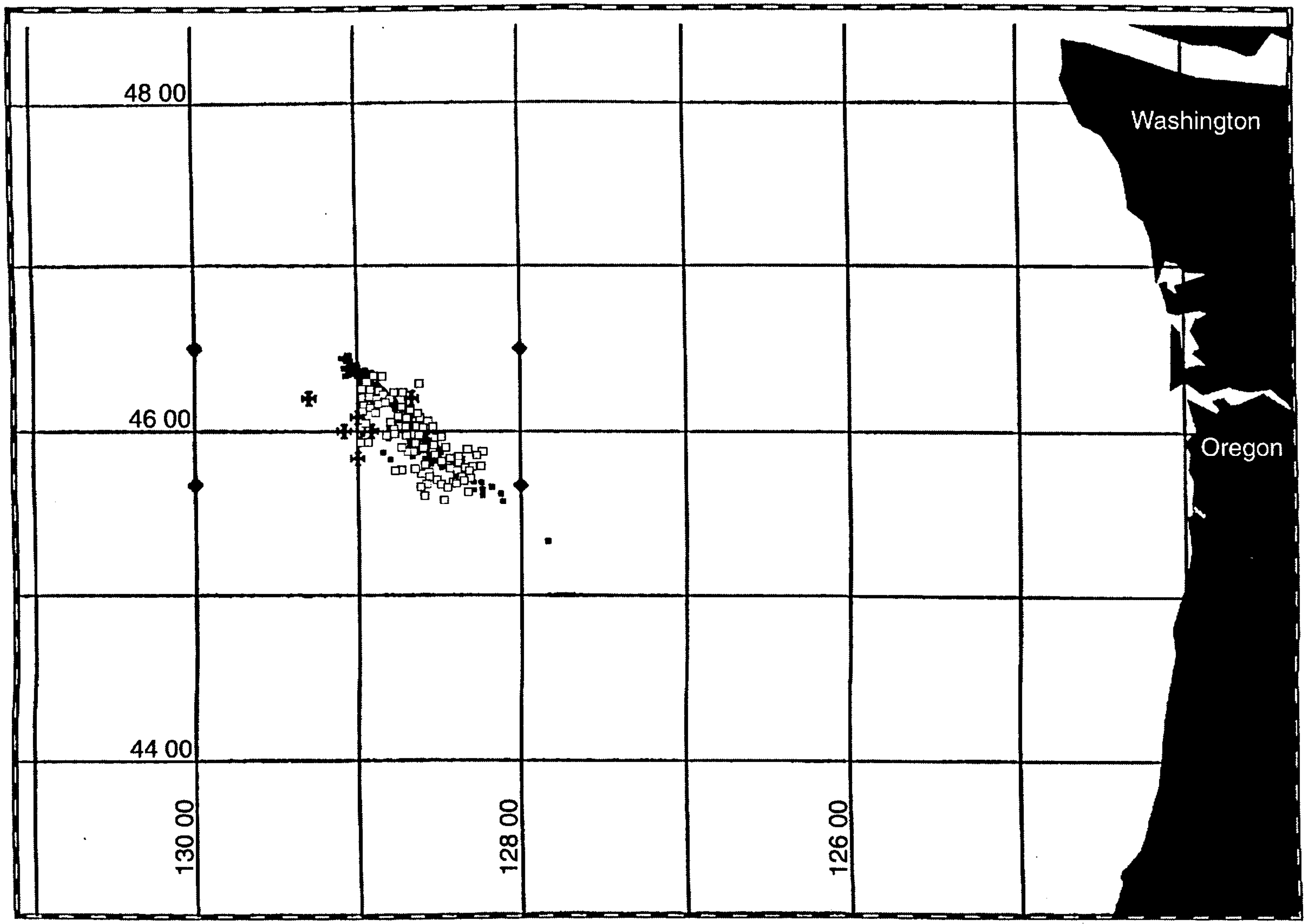



Figure l0.--Comparative locations of blue whale calls provided by the autonomous array (dark) and by SOSUS (light) relative to the Oregon/Washington coastline.

Table 1. Dection of fin whale calls via SOSUS during the NOAA ship Surveyor cruise. Note *=fin whales observed from the Surveyor. PDT= Pacific Daylight Time.

| Date | Local Time (PDT) | Position | Notes |
|---|---|---|---|
| 20 July 1994 | 2130 - 2200 hrs. | ~ 48.5° N | |
| 21 July 1994 | 0000 - 0300 hrs. | ~ 47.5° N | |
| 24 July 1994 | 1025 - 1045 hrs. | ~ 47.5° N | Lots of ship noise |
| 25 July 1994* | 1300 - 1600 hrs. | ~ 46.0° N | |
| | 1700 - 1900 hrs. | ~ 47.5° N | Strong signal |
| | 1700 - 1900 hrs. | ~ 40.0° N | |
| | 2300 - 0100 hrs. | ~ 48.0° N | |
| 26 July 1994* | 0500 - 0900 hrs. | ~ 47.5° N | |
| | 1000 hrs. | ~ 48.0° N | |
| 27 July 1994* | 0300 - 0600 hrs. | ~ 43.0° N | |
| | 1400 - 1600 hrs. | ~ 44.5° N | |
| | 2200 - 2220 hrs. | ~ 43.75° N | |
| | 2200 - 0030 hrs. | ~ 43.2° N | |
| 28 July 1994 | 0430 - 0830 hrs. | ~ 46.5 - 47.0° N | "Loud" ship after 0745 |
| | 1700 - 2100 hrs. | ~ 41.5° N | |
| | 2200 - 0100 hrs. | ~ 45.5° N | |
| 29 July 1994* | 0800 - 0900 hrs. | ~ 43.45° N | |
| | 1900 - 2000 hrs. | ~ 43.75° N | |
| | 2300 - 0010 hrs. | ~ 48.0° N | |
| 30 July 1994 | 1800 - 2000 hrs. | ~ 47.0° N | |
| 31 July 1994* | 0100 - 0200 hrs. | ~ 47.0° N | |
| | 0300 hrs. | ~ 45.5° N | |
| | 0600 - 0800 hrs. | ~ 44.25° N | |
| | 0900 - 1300 hrs. | ~ 45.5°N | |
| 01 August 1994 | 0100 - 0130 hrs. | ~ 47.0° N | |
| | 0400 - 0510 hrs. | ~ 46.5° N | Ship noise |

Table 2. Detection of sperm whale calls via SOSUS during the NOAA ship Surveyor cruise. Note *=sperm whales observed from the Surveyor. PDT= Pacific Daylight Time.

| Date | Local Time (PDT) | Notes |
|---|---|---|
| 20 July 1994 | 1800 - 2000 hrs. | |
| 21 July 1994 | 0100 - 0200 hrs. | |
| 22 July 1994 | 0000 - 0100 hrs. | |
| | 0600 - 0700 hrs. | |
| 23 July 1994* | 0300 - 0700 hrs. | Heard all day, especially at these times |
| | 0800 - 1100 hrs. | |
| | 1400 - 1500 hrs. | |
| 24 July 1994* | 1000 - 1200 hrs. | |
| | 1900 - 2000 hrs. | |
| | 2100 - 2200 hrs. | |
| 25 July 1994* | 0000 - 2400 hrs. | Heard all day |
| 26 July 1994 | 1000 - 1230 hrs. | Heard all day, especially at these times |
| | 2200 - 2300 hrs. | |
| 27 July 1994* | 0500 - 0600 hrs. | |
| 28 July 1994 | 1500 - 1600 hrs. | Very sporadic |
| | 1700 - 1900 hrs. | |
| | 2200 - 2300 hrs. | |
| 29 July 1994 | 1800 - 2000 hrs. | |
| 30 July 1994* | 0500 - 0600 hrs. | |
| | 1300 - 1500 hrs. | |
| | 2200 - 2300 hrs. | |
| 31 July 1994* | 1100 - 1200 hrs. | |
| 01 August 1994 | 1600 - 1700 hrs. | |

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