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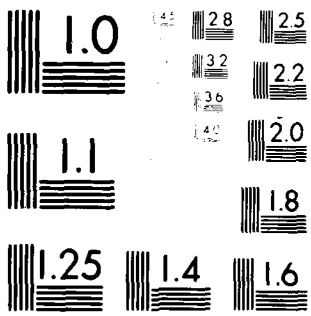
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Technical Report 732

# MEASURING ACOUSTIC NOISE AROUND KAHOOLAWE ISLAND

WA Friedl
PO Thompson

October 1981

Prepared for
Naval Surface Weapons Center
Navy Science Assistance Program



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NAVAL OCEAN SYSTEMS CENTER
SAN DIEGO, CALIFORNIA 92152

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AN ACTIVITY OF THE NAVAL MATERIAL COMMAND

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Technical Director

## ADMINISTRATIVE INFORMATION

This report summarizes work completed by the Naval Ocean Systems Center (NOSC), Code 512, on NSAP Project TH-1-80, "Measurement of Acoustic Noise Around Kahoolawe". CDR J. W. Carlmark, USN, COMTHIRDFLT N-33, and C. H. Sturtevant, NOSC Code 18 and NSAP advisor to COMTHIRDFLT coordinated the effort. The P-3 aircraft was from VP-17, PATWING TWO, NAS Barbers Point.

NOSC personnel on the flight were W. A. Friedl, Code 512, Cruise Leader; D. K. Ljungblad, Code 5131; J. M. Stallard, Code 512; and P. O. Thompson, Code 512. E. T. Nitta, National Marine Fisheries Service, Hawaii Laboratory, accompanied them. A. E. Murchison, NOSC Code 512, observed from Kihei, Maui Island, during the exercise.

Friedl and Thompson analyzed the data.

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Under authority of
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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Seven SSQ-57A sonobuoys were monitored for seven hours from a P-3 aircraft during a surface gunfire operation north of Kahoolawe Island, Hawaii, in February 1980. Whale locations and activity were also monitored from the aircraft and from Maui Island during the exercise. Humpback whale (*Megaptera novaeangliae*) phonations dominated the ambient noise field during the exercise. The phonations' fundamental components ranged between 100 Hz and 3 kHz. The calculated gunfire source level in the water was approximately 10 dB below the whales' phonation level; the gunshots' peak energy was near 70 Hz. We saw whales swimming, lying still, diving, surfacing and, in two isolated instances, breeching and lob-tailing. No standards exist to evaluate the effects of the noise on marine mammals.

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However, we cannot relate the movements and activities of whales observed during the exercise to any obvious airborne, surface or subsurface causes.

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## OBJECTIVES

1. Measure waterborne noise generated during naval gunfire operations off Kahoolawe Island, Hawaii.

2. Observe location and behavior of marine mammals in the waters off Kahoolawe Island during gunfire exercises.

## RESULTS

1. Humpback whale (*Megaptera novaeangliae*) phonations dominated the ambient noise field during the exercise.

2. The phonations' fundamental components ranged between 100 Hz and 3 kHz. The calculated gunfire source level in the water was approximately 10 dB below the whales' phonation level; the gunshots' peak energy was near 70 Hz.

3. Whales were observed swimming, lying still, diving, surfacing and, in two isolated instances, breeching and lob-tailing.

4. No standards exist to evaluate the effects of noise on marine mammals. However, we cannot relate the movements and activities of whales observed during the exercise to any obvious airborne, surface or subsurface causes.

## RECOMMENDATIONS

1. Use calibrated sensors and receivers to obtain absolute sound pressure levels in any future measurements.

2. Repeat the exercise twice in FY 81. Measure waterborne noise during a gunfire exercise when humpback whales are abundant in waters off Kahoolawe Island (i.e., December – March) and again when humpback whales are absent from those waters (i.e., July – October).

3. Use P-3 aircraft for any future measurements. Locate and plot sonobuoy position hourly during the measurement exercise.

## INTRODUCTION

### BACKGROUND

The project gathered baseline data on waterborne noise generated during gunfire exercises by a surface vessel off Kahoolawe Island, Hawaii. COMTHIRDFLT requested the data as input for plans to allow the Navy to conduct necessary training off Kahoolawe while minimizing the activities' effects on the environment (ref 1). No standards exist to evaluate the effects of the noise on marine mammals and thus the task could not assess the impact of the exercise on marine mammals.

### OBJECTIVES

The project team was tasked to measure waterborne noise generated during naval gunfire operations off Kahoolawe Island, Hawaii. Also, the team was directed to observe the location and behavior of marine mammals in the waters off Kahoolawe Island during the gunfire exercises.

## PROCEDURES

### FIELD PROCEDURES

Seven SSQ-57A sonobuoys were dropped from a P-3 aircraft near the training area off Kahoolawe Island on 5 Feb 1980. The received signal level adjustments of the sonobuoys were set at 20 dB attenuation to compensate for expected sound levels. The sonobuoys were monitored from the aircraft for seven hours during gunnery exercises by the USS OUELLET (FF-1077). The gun was a 5-inch (127-mm), 54 caliber, MK 42. All rounds were puff HTC ammunition. Sonobuoy data and comments were recorded from the aircraft receiver console on 1-inch (1.5-cm) magnetic tape at 7.5 in/sec with a Honeywell 5600 C tape recorder.

Whale position, heading and activity were monitored from the aircraft throughout the flight. Two or more observers were on whale watch while the aircraft was on station. Whale position and heading were plotted on the aircraft's plotting sheet. Additional whale observations were made by watch officers on OUELLET and by an observer on the roof of the Royal Mauian condominium in Kihei, Maui.

A bathythermograph, dropped from the aircraft at the end of the measurement period, measured water temperature. We used the temperature data to calculate sound speed during the measurements (ref 2).

1. COMTHIRDFLT Message 211621Z Jan 1980.
2. Urich, R. J., Principles of Underwater Sound for Engineers, McGraw-Hill Book Co., 1967.

## LABORATORY PROCEDURES

We used the aircraft flight logs and plotting sheets, the ship's deck log and the observers' notes to determine the sonobuoys', ship's, and whales' locations during the measurement period.

We compared relative signal level *vs* frequency for ambient noise, whale phonations and gunfire noise recorded during the exercise. Analysis instruments were as follows: a Spectral Dynamics Model SD330 Real Time Analyzer, a Hewlett-Packard Model 403 B RMS Voltmeter, and a Federal Scientific Corporation Model UA-500A-1 Ubiquitous Spectrum Analyzer - Averager with X-Y Plotter. We calculated transmission loss according to ref 2.

We compared gunfire noise with nearly coincident ambient noise. We located soniferous whales by triangulation to the sonobuoys, using differences in arrival times of distinctive phonations and a sound speed of 1532 m/sec. We assumed a whale source level of 185 dB re 1 μPa at 1m in a 1-Hz band (= spectrum level) (ref 3). We also assumed that all waterborne gunfire noise was transmitted through the ship's hull and air-to-water propagation was insignificant (ref 4).

## RESULTS

Table 1 summarizes the operation's chronology. Figure 1 shows the sonobuoy pattern and ship positions. The sonobuoys were in a wedge pattern and all hydrophones were at 60 ft (18 m). Sonobuoy 2 was between the firing area and Kahoolawe Island, in water of about 42 fathoms (77 m). Thus, OUELLET generally fired toward sonobuoy 2. The six other sonobuoys were dropped along two lines, radiating north and northeast from the firing zone, in water deeper than 100 fathoms (182 m). These buoys, then, were to the side of or behind the shot direction.

Humpback whale (*Megaptera novaeangliae*) phonations were the most prevalent ambient noise source. The phonations were continuous throughout the observation period. Ship, small boat, and aircraft engine noises were also intermittent parts of the noise field.

With the exception of the data from sonobuoy 12, the shots were detectable, both aurally and with the spectrum analyzers, in the output of all sonobuoys. A tape recorder malfunction prevented us from recording data from sonobuoy 12. We reviewed data from the entire exercise and selected the five-shot sequence at 0851 hours (table 1) for further analyses because (1) at that time, the sonobuoys were close to their deployed positions, and (2) the received levels were as high as any recorded. Figure 2 shows shot spectra and nearly simultaneous ambient noise spectra for the 0851 shot sequence from sonobuoys 2, 15 and 24. The spectra show the shot energy increased the noise below 1 kHz at all three buoys.

3. Thompson, P. O., W. C. Cummings and S. J. Kennison, Sound Production of Humpback Whales, *Megaptera novaeangliae*, in Alaskan Waters, ms submitted to the Journal of the Acoustical Society of America, 1980.
4. Cook, J. C., T. Goforth and R. K. Cook, Seismic and Underwater Responses to Sonic Boom, Journal of the Acoustical Society of America, 51 (2, part 3), p 729-741, February 1972.

| LOCAL TIME | EVENT |
|---|---|
| 0640 | On Station: 20°37'N, 156°46'W |
| 0656 | Deployed sonobuoy 2: 20°35'N, 156°39'W |
| 0700 | Deployed sonobuoy 7: 20°40'N, 156°34'W |
| 0702 | Deployed sonobuoy 12: 20°38'N, 156°33'W |
| | Deployed sonobuoy 15: 20°37'N, 156°39'W |
| 0708 | Deployed sonobuoy 5: 20°44'N, 156°41'W |
| 0709 | Deployed sonobuoy 1: 20°40'N, 156°41'W |
| 0710 | Deployed sonobuoy 24: 20°38'N, 156°41'W |
| 0813 | OPEN FIRE. ONE ROUND |
| 0845 | ONE ROUND |
| 0847 | ONE ROUND |
| 0849 | TWO ROUNDS |
| 0851 | FIVE ROUNDS |
| 1032 | ONE ROUND |
| 1046 | ONE ROUND |
| 1049 | ONE ROUND |
| 1050 | ONE ROUND |
| 1052 | ONE ROUND |
| 1149 | FOUR ROUNDS |
| 1155 | ONE ROUND |
| 1157 | ONE ROUND |
| 1205 | ONE ROUND |
| 1245 | ONE ROUND |
| 1247 | ONE ROUND |
| 1352 | XBT Drop 20°45'N, 156°34'W |
| 1359 | ONE ROUND |
| 1401 | ONE ROUND |
| | Aircraft off station 20°46'N, 156°54'W |

Table 1. Operation chronology.

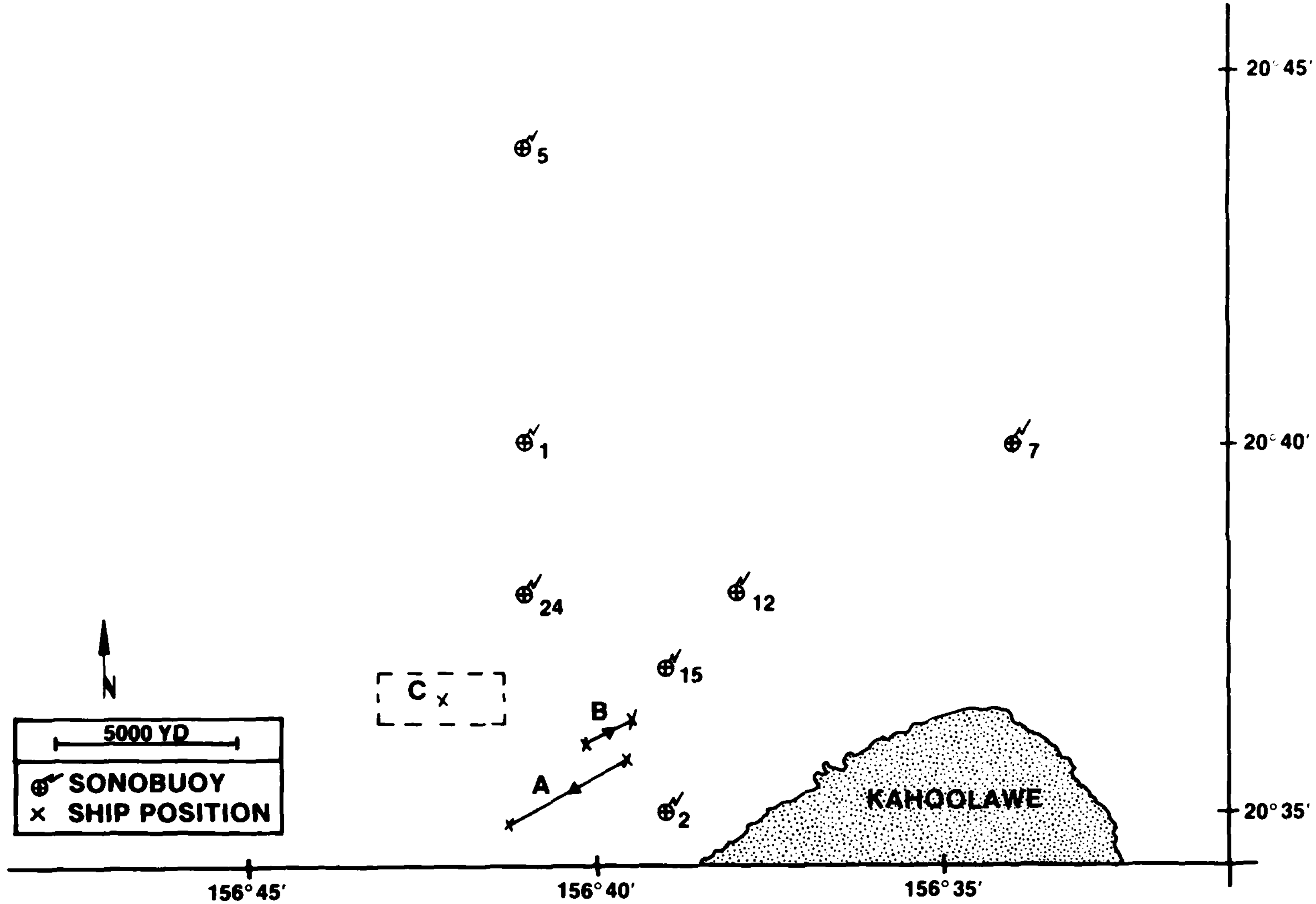


Figure 1. Sonobuoy drop positions and ship position during the exercise. "A" marks ship's track from 0800 to 0817. "B" marks the track from 0843 to 0852, during which the best shot data were recorded. "C" indicates the area in which the ship operated from 1030 to 1401.

At sonobuoy 2, the ambient noise spectrum increased with frequency below 500 Hz (fig 2a). Although shot spectra generally exceeded the ambient noise spectra below 1 kHz, humpback whale phonations were distinguishable in the shot spectra, particularly the spectra from sonobuoy 24 (fig 2c). Maximum energy in the shot spectrum was around 70 Hz.

A distinct humpback whale phonation was recorded at 0851, just after the five-shot sequence. Using time-of-arrival differences, we calculated the source whale's position as 20° 47.2'N latitude, 156° 37.5'W longitude, about 2775 m south of Hekili Point on Maui Island. The whale's phonation was tonal at approximately 500 Hz.

Sonobuoy 15 was closest to OUELLET during the 0851 shot sequence (fig 1). Figure 2b shows that the gunshot data recorded at sonobuoy 15 has a very good signal-to-noise ratio. The gunshot spectrum from sonobuoy 15 has its major peak level in the 63- to 125-Hz octave (fig 2b). At sonobuoy 24, peak energy in that octave is also prominent, but peaks from whale phonations between 100 and 200 Hz, around 600 Hz, and above 1 kHz equal or exceed the gunshot peak level.

Our source level calculations used phonation and shot level data from sonobuoy 24. We used levels from an individual gunshot to limit contamination of the data by whale phonations because phonation contamination of the gunshot signal increased when we analyzed multiple shots. Our refererence phonation had most of its energy in its fundamental component near 500 Hz. Our level analyses showed that, relative to the level of the phonation fundamental, the gunshot level was –4 dB at its major peak, –2 dB in the 63- to 125-Hz octave, and +2 dB broadband (20 Hz to 10 kHz).

Source level calculations are summarized in table 2. We assumed a 185-dB re 1 $\mu$Pa at 1m whale phonation source level and calculated an 85-dB transmission loss for the 18.2-km whale-to-sonobuoy range to compute a 100-dB phonation received level at sonobuoy 24. The gunshot broadband received level was +2 dB relative to the phonation, which equals a 102-dB received level at sonobuoy 24. For the 4-km ship-to-sonobuoy distance, we calculated a transmission loss of 73 dB. We added the loss to the calculated received level at sonobuoy 24 and produced an estimated gunshot source level at the ship's hull of 175 dB re 1 $\mu$Pa at 1m broadband. Using the same rationale, the estimated octave band and peak spectrum levels at the ship's hull are 171 dB and 169 dB, respectively.

Tables 3 and 4 and figure 3 summarize the whale observations. Additionally, shipboard observers recorded five sightings of three individual whales: one whale at 0800 and 0813, the second whale at 0904, and the third at 1357 and 1402. The 0800/0813 whale was sighted from the aircraft at 0809. The whale was swimming on the surface, parallel to the ship's track, about 1,000 yds (914 m) from OUELLET.

Airborne observers sighted two groups of whales; other sightings were of solitary or paired animals. One group of four whales was in the Auau Channel between Lanai and Maui Islands (cf 0932 and 1009 sightings, fig 3). The other group of five (or six) whales was inside the buoy pattern (cf 1117, 1158, and 1215 sightings, fig 3), and moved slowly southward during the observation period. This group was likely the "pod" and "school" of whales recorded in the ship's log at 1406 and 1455, respectively.

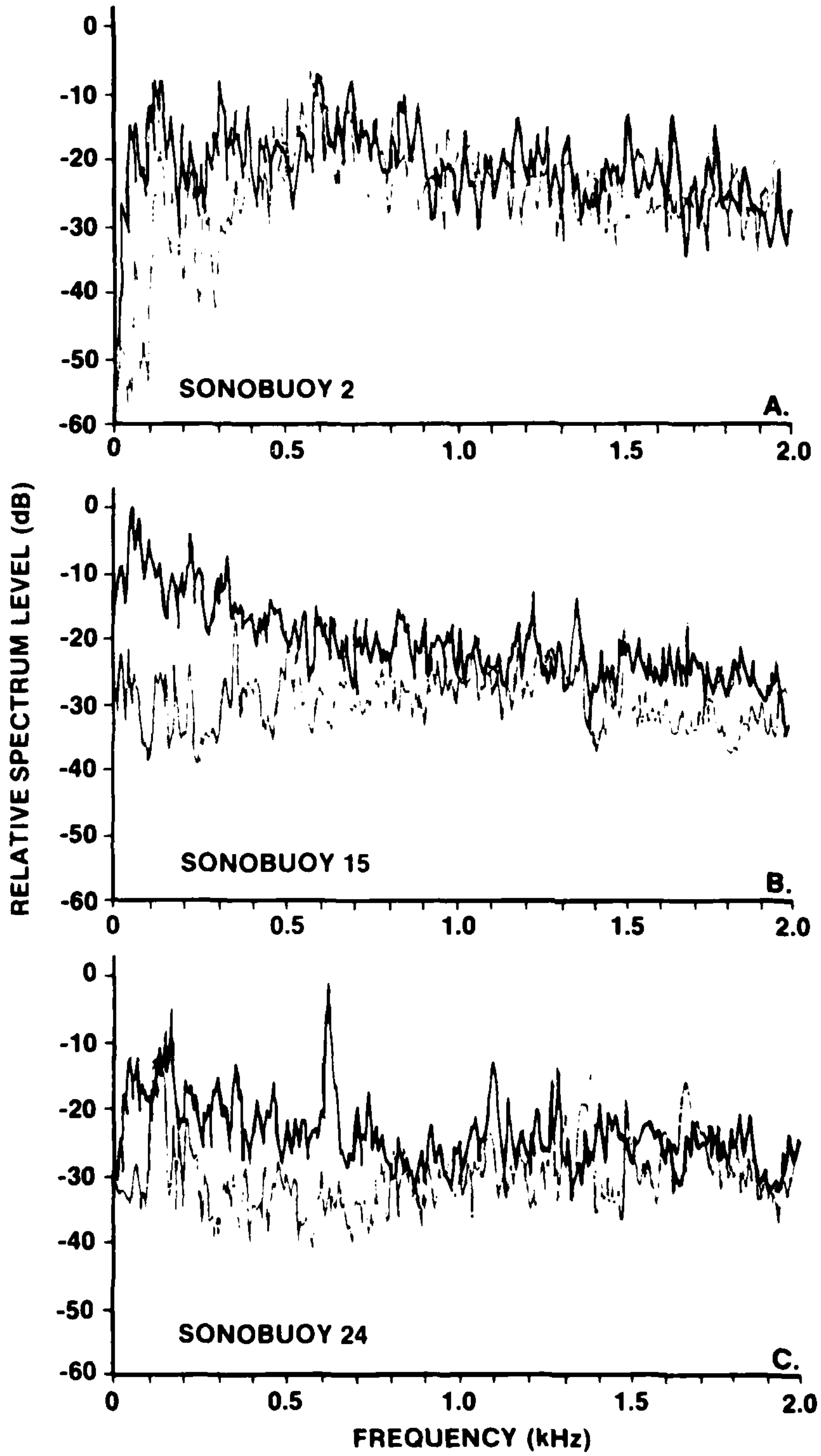


Figure 2. Peak spectra for gunshots and ambient noise from three sonobuoys. Light line is ambient noise about 0850, before a gunshot sequence. Dark line is noise recorded during 0851 five-shot sequence. Each line represents peak values from 32 spectra. A: Spectra received at sonobuoy 2. B: Spectra received at sonobuoy 15. C: Spectra received at sonobuoy 24. Peaks near 0.15 and 0.60 kHz are from humpback whale phonations during the gunshot sequence.

PHONATION

| | | | |
|---|---|---|---|
| Assumed whale source level | 185 dB | | |
| Transmission loss for 18.2-km whale-to-sonobuoy 24 range | 85 db | | |
| Calculated received level at sonobuoy 24 | 100 dB | | |

GUNSHOT RECEIVED LEVEL AT SONOBUOY 24

| | Spectrum Level | Octave Band Level | Broadband Level |
|---|---|---|---|
| Relative to phonation | −4 dB | −2 dB | +2 dB |
| Calculated value | 96 dB | 98 dB | 102 dB |

GUNSHOT SOURCE LEVEL AT "OUELLET"

| | | | |
|---|---|---|---|
| Transmission loss for 4-km ship-to-sonobuoy 24 range | 73 dB | | |

| | Spectrum Level | Octave Band Level | Broadband Level |
|---|---|---|---|
| Calculated value | 169 dB | 171 dB | 175 dB |

Table 2. Source level calculations.

| Time | Number | Course (° True) | Location N. Latitude | W. Longtitude |
|---|---|---|---|---|
| 0740 | 2 | 360 | 20°48′ | 156°43′ |
| 0750 | 3 | 330 | 20°51′ | 156°46′ |
| 0758 | 2 | 090 | 20°45′ | 156°39′ |
| | 1 | 090 | 20°45′ | 156°37′ |
| 0759 | 2 | UNK | 20°47′ | 156°40′ |
| 0800 | 2 | 210 | 20°37′ | 156°45′ |
| 0801 | 1 | 210 | 20°50′ | 156°43′ |
| 0809 (A) | 1 | 245 | 20°36′ | 156°40′ |
| 0812 | 1 | 210 | 20°44′ | 156°34′ |
| 0843 (B) | 2 | 180 | 20°48′ | 156°40′ |
| 0932 | 4 | UNK | 20°50.2′ | 156°44′ |
| 0939 | 2 | 180 | 20°46′ | 156°40′ |
| 0947 | 1 | 330 | 20°48.6′ | 156°45.5′ |
| 0950 | 3 | 180 | 20°42.7′ | 156°42′ |
| 0951 | 1 | UNK | 20°44′ | 156°43′ |
| 0959 | 2 | 270 | 20°52′ | 156°47′ |
| 1009 | 4 | 060 | 20°49.5′ | 156°46.5′ |
| 1031 | 1 | 240 | 20°44′ | 156°46′ |
| 1117 | 5 | 210 | 20°42.5′ | 156°39′ |
| 1124 | 1 | 200 | 20°44.8′ | 156°45′ |
| 1134 | 1 | UNK | 20°47.2′ | 156°42′ |
| 1158 | 3 | 180 | 20°41′ | 156°38.5′ |
| 1204 | 1 | 050 | 20°37.5′ | 156°37′ |
| 1215 (C) | 3 | 190 | 20°40′ | 156°39′ |
| 1337 (D) | 1 | 180 | 20°44.7′ | 156°48′ |

Notes:

(A) Whale also sighted from OUELLET 0800-0904. 0800 Log entry noted whale course *parallel* to the ship (245° heading).

(B) Adult and calf.

(C) Two whales tail-lobbing for less than 2 minutes.

(D) Breeching adult whale.

UNK Course unknown.

Table 3. Summary of whale observations from the P-3 aircraft.

| Time | Observation |
|---|---|
| 0812 | Adult whale, moving northerly in Maalaea Bay approximately 1 mile from shore.<br>2 Dives: 3.4 min and 5+ min.<br>Lost contact: 0825 |
| 0823 | Whale reported about 3 mi NW of OUELLET. |
| 0902 | 2 whales sighted from sonobuoy 7. |
| 0938 | 2 whales - the same observed at 0902 - heading toward Maalaea Bay. |
| 1022 | Whale off Maalaea Bay. Approximately 2.5 mi from shore.<br>2 Dives: 0.6 min and 1.9 min. |
| 1133 | Adult whale approximately 3.5 mi offshore.<br>9 Dives: 1.7 min, 3.6 min, 5.5 min, 2.5 min, 3.8 min, 1.0 min, 0.7 min, 1.1 min, 5.2 min<br>Whale moving slowly north between dives 4 and 5; moving slowly south after dive 9.<br>Lost contact: 1206 |

Table 4. Summary of whale observations from Kihei on Maui Island.

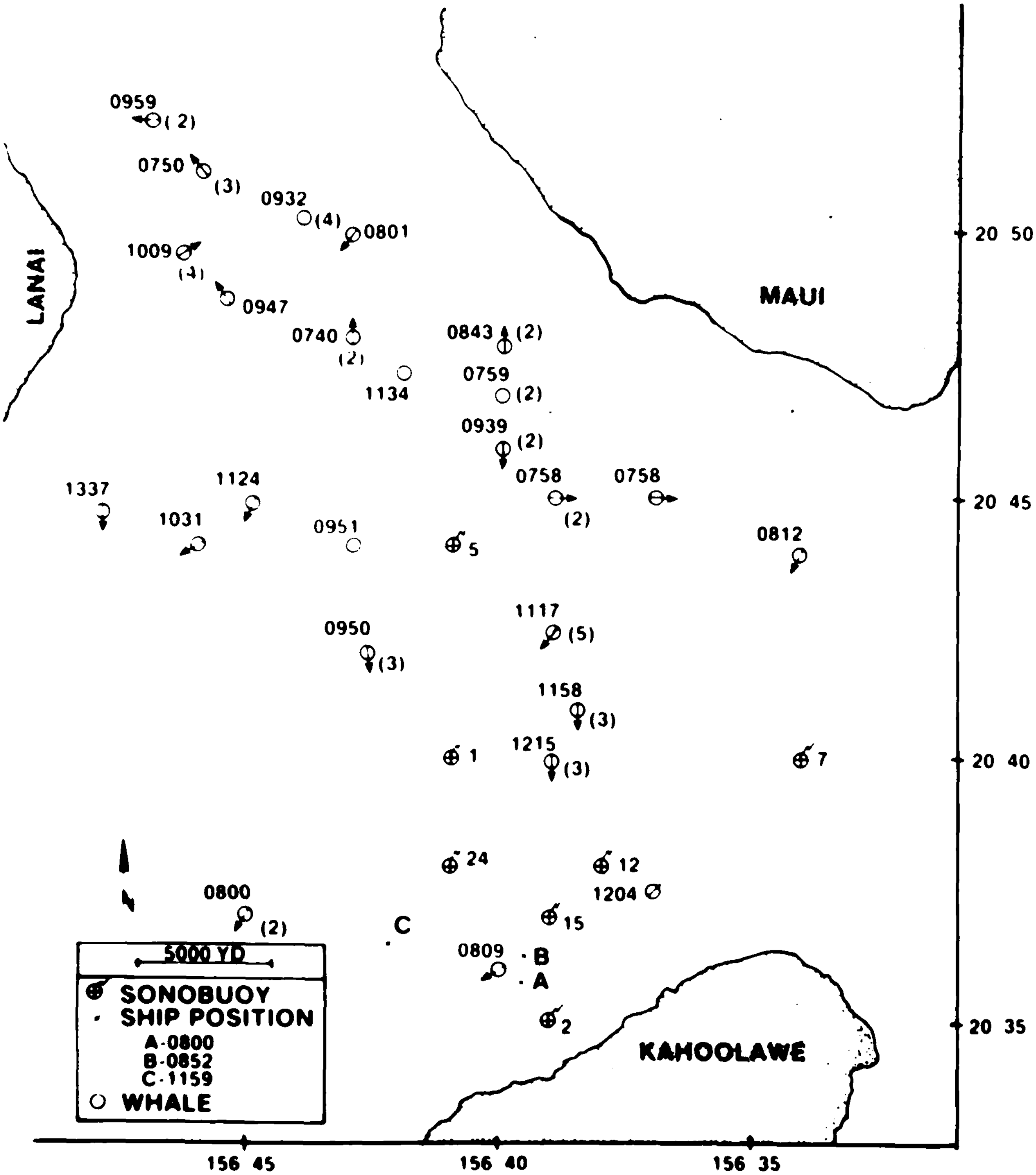


Figure 3. Summary of whale observations from the P-3 aircraft. Arrows indicate heading, if noted. Bracketed numbers indicate the number of whales sighted. Whale locations are given in Table 1.

The aircraft's altitude was 150 m to 350 m while we were on station. Most sightings were brief because of the aircraft's speed. We observed whales swimming, lying still, diving, surfacing and in two solitary instances, breeching and lob-tailing. The whales did not seem to respond to the aircraft during the brief sighting periods.

## DISCUSSION

Our estimated gunfire source levels are based on estimates of humpback whale phonation source levels and would vary if a different phonation source level were used. In 1975, NOSC personnel observed whales and recorded humpback whale phonations with a calibrated hydrophone system from a Navy TRB craft in the same interisland area. Over a three-day period, ten separate recordings were made. Source levels were estimated from the seven best recordings and averaged 186 dB re 1 $\mu$Pa at 1m with a standard deviation of ±5 dB. Based on the 1975 data, our assumed phonation source level is reasonable and estimated source levels are likely within 5 dB of actual values. We assume that inter-whale variations of adult humpback whale phonation source levels are small, both between whales and over time, and thus based our assumed phonation source level on the 1975 data. The values provide reasonable estimates of gunfire source levels from our measurements.

Although the estimated gunfire source level depends on the assumed source level of the whale phonations, the relative levels remain constant. Our data show the gunshot source level was approximately 10 dB below the whale's phonation source level. No standards exist to evaluate the effects of the noise on marine mammals, but our results indicate the relative magnitude of the gunfire in the whales' natural sonic environment. The gunfire noise was brief and impulsive; the whale phonations were sustained and extended.

Absolute sound pressure measurements could be made with calibrated sonobuoys and receivers (ref 5 and 6). Logistics and time limits prevented us from using calibration information for the SSQ-57A sonobuoys and from calibrating the receiver/recorder system to measure absolute sound pressures on this operation.

Between Kahoolawe and Maui Islands, water movement is weak and variable (ref 7 and 8). We estimated maximum sonobuoy drift for the observation period from wind, tide, and current information for 5 Feb 1980 (fig 4). Our source level calculations are based on nominal sonobuoy positions because data were taken within two hours of the sonobuoy drop. The estimated sonobuoy drift would change the transmission loss values in the source level calculations. We estimate that the change in source level resulting from maximum sonobuoy drift would not exceed 2 dB.

5. NUC TP 547, Acoustic Source Levels of Four Species of Small Whales, by J.F. Fish and C.W. Turl, December 1976
6. Available to qualified users.
7. U. S. Department of Commerce, National Oceanic and Atmospheric Administration, National Ocean Survey, Tide Tables 1980: West Coast of North and South America, U. S. Government Printing Office, 1979.
8. U. S. Department of Commerce, National Oceanic and Atmospheric Administration, National Ocean Survey, Tidal Current Tables 1980: Pacific Coast of North America and Asia, U. S. Government Printing Office, 1979.

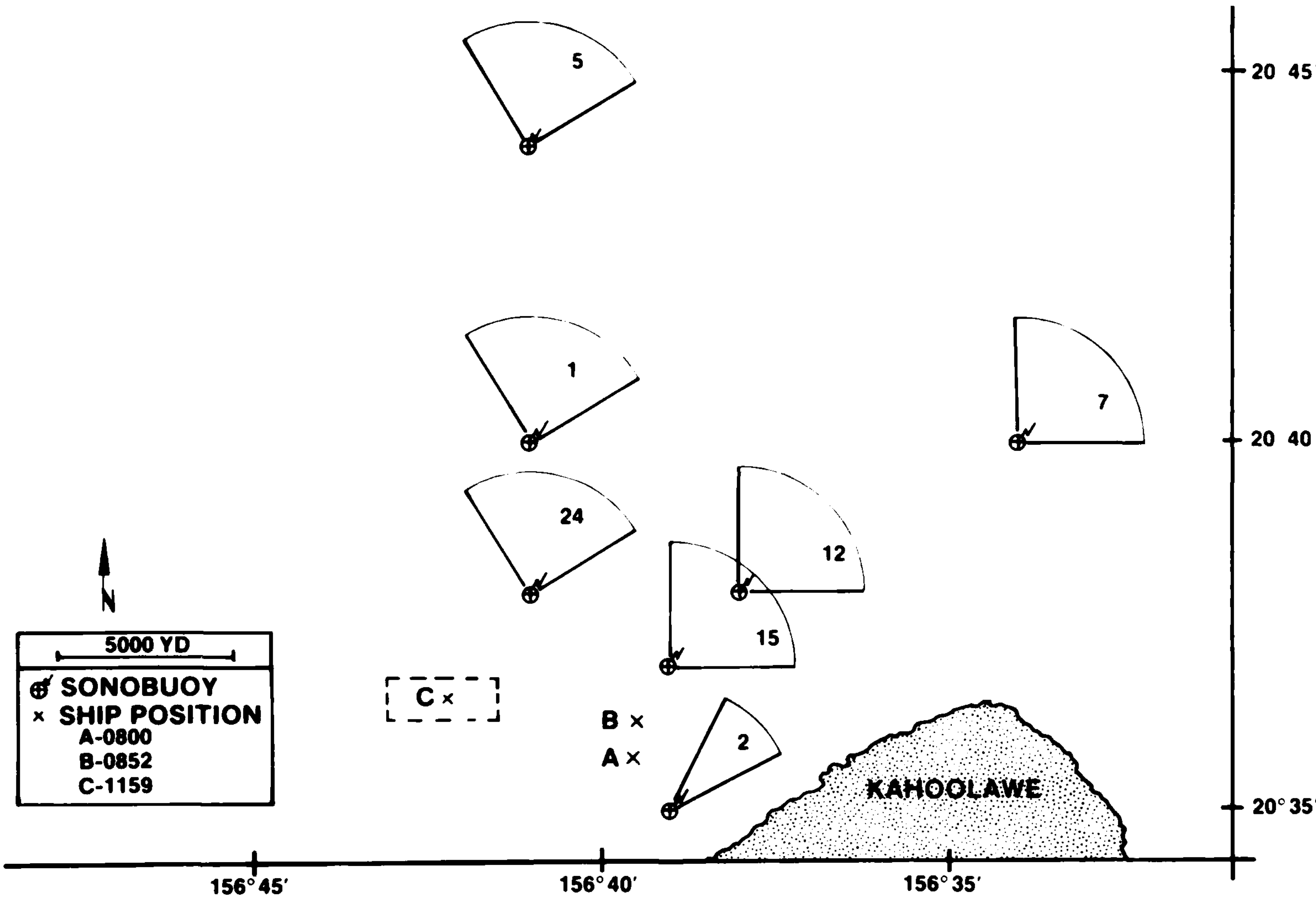


Figure 4. Estimated drift ranges for the sonobuoys during the 7-hour exercise.

The major peak of gunshot energy was around 70 Hz (fig 2). Peak energies for humpback whale phonations were at 500 Hz. In the spectrum summation mode used to produce fig 2, shot spectra also include whale phonation components. Furthermore, the shot peak values are the highest levels from five shots and the spectra are not properly comparable to the level of a single whale phonation. Thus, we selected single shots for comparison to eliminate contamination of the shot spectrum.

The ambient noise spectrum increased with frequency below 500 Hz at sonobuoy 2 (fig 2a), most likely from shallow-water bottom absorption of low-frequency shot energy and mid-frequency noise from OUELLET. In deeper water, ambient noise spectra normally show a slight decrease in level with increasing frequency. The spectra from sonobuoys 15 and 24 do not show this decrease (fig 2b and c) and thus indicate that the ambient noise we recorded contained many sound sources not normally found in typical deep-water ambient noise spectra (ref 2). In this case, the additional noise is almost all from humpback whale phonations during the 32-spectra sampling periods. Near and distant source whales increased the ambient noise spectrum, particularly for sonobuoy 24, but also at sonobuoys 2 and 15. Typically, the phonations received at a particular time were from, at most, six source whales. Around the time of the 0851 five-shot sequence, phonations from three source whales were recorded at sonobuoy 2, while four or five were recorded at sonobuoys 15 and 24. Thus, of the whales we saw, only a portion were likely to have produced phonations during the exercise.

We saw whales in the waters between Maui, Lanai, and Kahoolawe Islands throughout the observation period. We cannot relate the movement and activities observed to any obvious airborne, surface, or sub-surface cause.

Our whale observations were limited to seeing animals at the surface, counting animals and noting activities, all in a brief period for each sighting. The P-3 aircraft provided excellent area coverage for observations of water-surface events. The aircraft's speed, however, limited sustained observation of any single event.

## CONCLUSIONS

Our measurements are unique. Resources were limited for the project, and use of land, sea, and airborne assets and multi-agency personnel required careful coordination. Time restrictions prevented us from calibrating the taped data input from the sonobuoys to calculate absolute levels, but we estimated the gunshot source level at the ship's hull from relative values.

The ambient noise was dominated by humpback whale sounds. Using an estimated phonation source level and comparative received levels of both phonations and gunshots from sources at known locations, we estimated the underwater component of the gunshot source level to be 169 dB peak spectrum level and 175 dB broadband re 1 $\mu$Pa at 1m.

Without a distinct noise source of known source level, reasonable gunshot source level estimates are almost impossible to make. Thus, for gunshot source level measurements in the absence of whale phonations, calibrated sensors are mandatory. Obviously, whale source levels could also be determined from direct measurements with calibrated sensors.

The P-3 aircraft with calibrated sonobuoys and receivers is the best available system for noise measurement and whale observation. Detailed observations of a small area or of a specific animal would require a different platform, preferably an aircraft of much slower speed. Platform choice thus involves measurement, observation, and whale-platform interaction considerations. The P-3 aircraft was well-suited for this exercise.

## RECOMMENDATIONS

1. Use calibrated sensors and receivers to obtain absolute sound pressure levels in any future measurements.

2. Repeat the exercise twice in FY 1981. Measure waterborne noise during a gunfire exercise when humpback whales are abundant in waters off Kahoolawe Island (i.e., December – March) and again when humpback whales are absent from those waters (i.e., July – October).

3. Use P-3 aircraft for any future measurements. Locate and plot sonobuoy position hourly during the measurement exercise.

## REFERENCES


1. COMTHIRDFLT Message 211621Z January 1980.

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