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14. ABSTRACT
Aerial surveys of marine mammals were performed as part of the Marine Mammal Monitoring on Navy Undersea Acoustic Ranges (3MR) program. Surveys were performed in three regions: a) Pacific Missile Range Facility (PMRF), Barking Sands, Kauai (BSURE and BARSTUR ranges; Jul 12-Nov 17, 2002); b) Bahamas (Northwest Providence Channel and AUTEC range; Jan 4-12, 2003); and c) main Hawaiian Islands (Feb 21–Apr 5, 2003). The mission was to identify species and record positions and composition of all marine mammal pods sighted. These data were made available to co-investigators (Martin and Moretti) of the 3MR program in order to correlate the visual positions with acoustic localizations using Navy assets. Methods used were consistent with those of modern distance sampling theory.

15. SUBJECT TERMS
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Results of Marine Mammal Surveys on U.S. Navy Underwater Ranges in Hawaii and Bahamas

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Table of Contents

Executive Summary

Aerial surveys of marine mammals were performed as part of the Marine Mammal Monitoring on Navy Undersea Acoustic Ranges (3MR) program. Surveys were performed in three regions: a) Pacific Missile Range Facility (PMRF), Barking Sands, Kauai (BSURE and BARSTUR ranges; Jul 12-Nov 17, 2002); b) Bahamas (Northwest Providence Channel and AUTEC range; Jan 4-12, 2003); and c) main Hawaiian Islands (Feb 21–Apr 5, 2003). The mission was to identify species and record positions and composition of all marine mammal pods sighted. These data were made available to co-investigators (Martin and Moretti) of the 3MR program in order to correlate the visual positions with acoustic localizations using Navy assets. All surveys were flown in a twin-engine Partenavia aircraft at 100 knots airspeed and 244 m altitude. Four personnel participated on each flight including one observer on each side of the aircraft, data recorder and pilot. Methods used were consistent with those of modern distance sampling theory.

For the PMRF surveys (Jul 12 - Nov 17, 2002), a total of nine sightings were recorded during 10 surveys involving 15.1 hrs of effort, yielding a sighting rate of 0.60 sightings/hr. Sightings included three identified species (no. sightings): spotted dolphins (2), spinner dolphins (1), and short-finned pilot whales (1). Preliminary analysis of acoustic recordings from BSURE and BARSTUR hydrophones (S. Martin) suggested a correlation between overall aerial sightings and acoustic detections, mostly representing humpback and sperm whale vocalizations.

In the Bahamas (Jan 4-12, 2003), a total of 13 and 8 sightings were recorded in the AUTEC Range and Northwest Providence Channel (NPC) regions, respectively, during 12 surveys representing 26.1 hrs of survey effort. This yielded an overall sighting rate of .80 sightings/hr. Sightings included eight identified species: bottlenose dolphins (3), sperm whales (3), pygmy or dwarf sperm whales (2), short-finned pilot whales (1), rough-toothed dolphins (1), striped dolphins (1) and humpback whale (1).

For the main Hawaiian Islands (Feb 21-Apr 5, 2003), a total of 489 sightings were made during 16 surveys representing 64.9 hrs of effort, yielding a sighting rate of 7.53 sightings/hr. The majority (88%) of sightings were of humpback whales. Other confirmed species sightings included bottlenose dolphins (12), spinner dolphins (7), short-finned pilot whales (6), spotted dolphins (4), sperm whales (3), melon-headed whales (2), rough-toothed dolphins (2), dwarf or pygmy sperm whales (2), and pygmy killer whale (2). Of all species sighted, only humpback whales were seen with sufficient frequency to warrant estimation of abundance. Abundance estimates were derived using the program DISTANCE (Release 3.5). Shorestation data was used to derive an estimate of the probability of detection at the surface ($g(0) = .26$). This produced a corrected abundance estimate of 3,558 whales (95% CI: 2,927 - 4,189). When compared with previous abundance estimates for the period 1993-2000 using identical methods, the 2003 estimate represented a substantial reduction from the previous increasing trend. More data are needed to determine whether this reduction is anomalous or reliable.

Background

These surveys were conducted as part of the Marine Mammal Monitoring on Navy Undersea Acoustic Ranges (3MR) program (with co-PIs Dave Moretti and Steve Martin). The program mission was to use instrumented underwater naval ranges to detect and localize vocalizing marine mammals, then correlate those detections with visual sightings from aerial surveys. Principal investigators Moretti and Martin were responsible for the acoustic detection portions for the AUTEC and PMRF ranges, respectively. Those results will be summarized separately in their reports. This report will deal specifically with visual sightings of marine mammals.

An additional goal was to extend earlier work (Mobley et al., 2001) on tracking abundance trends of humpback whales during their winter residency in the main Hawaiian Islands. Results for the 2003 field season were added to the previous four years of survey data (1993, 1995, 1998, 2000) to complete a ten year time series (1993-2003).

This report is divided into three parts: a) surveys of the Pacific Missile Range Facility BSURE and BARSTUR underwater ranges off Kauai; b) surveys of the Bahamas (AUTEC Range and Northwest Providence Channel); and c) surveys of waters off the major Hawaiian Islands.

General Method

All survey methods used conformed to accepted distance sampling techniques (e.g., Buckland et al., 2001). Surveys followed pre-determined tracklines designed to permit maximum coverage of each study area (Figures 1, 3, 4 and 7). Starting points were randomly chosen per distance sampling methods (Buckland et al. 2001) so that the exact trackline configuration varied for each survey.

The survey aircraft was a twin-engine Partenavia Observer flying at a speed of 100 knots and an altitude of 244m (800 ft). Two experienced observers made sightings of all marine mammal species, one on each side of the aircraft. Sightings were called to a data recorder who noted the species sighted, number of individuals, presence or absence of a calf, angle to the sighting (using hand-held Suunto clinometers), and any apparent reaction to the aircraft. Additionally, GPS (Garmin GPS 92) locations and altitude were automatically recorded onto a laptop computer at 30-sec intervals, as well as manually whenever a sighting was made. Environmental data (seastate, glare and visibility) were manually recorded at the start of each transect leg and whenever conditions changed. The two data sources (manual and computer) were later merged into a single data file.

In cases where species identity was not clear upon initial sighting, locations were orbited to confirm species identity and pod composition (i.e., no. individuals and presence or absence of calves). In cases where species identity could not be determined, sightings were noted as unidentified dolphin, whale or cetacean (based on apparent size).

Part I. 2002 Pacific Missile Range Facility (PMRF) Surveys

The Pacific Missile Range Facility (PMRF) operates two contiguous underwater tracking ranges off the island of Kauai, Hawaii. The Barking Sands Tactical Underwater Range (BARSTUR) is located west of the island and consists of 42 bottom-mounted hydrophones covering an area of approximately 100 square nautical miles (http://www.globalsecurity.org). The Barking Sands Underwater Range Expansion (BSURE) is located northwest of the island and consists of 18 hydrophones which cover an area of approximately 880 square nautical miles.
We conducted a total of 10 bi-monthly surveys of the PMRF BSURE and BARSTUR ranges between July 12 and Nov 17, 2002 (Table 1).

Method

Transects were placed 4-nmi apart in the BARSTUR range and 14-nmi apart in the BSURE range (Note: past surveys have shown the maximum effective distance to be 2 nmi on each side of the plane). The greater density of effort in the BARSTUR range is due to the fact that the broadband phones in that area produce better signal-to-noise, thus permitting greater accuracy of acoustic localization (S. Martin, personal communication).

Visual sighting data will be compared with acoustic location data obtained using broadband hydrophones in the BARSTUR and BSURE ranges (acoustic portion to be performed by Steve Martin of SPAWAR). This permits ground-truthing of acoustic locations using accepted visual techniques (Note: These results will be reported separately by S. Martin) (see preliminary results summarized in Figure 3).

Results and Discussion

We performed 15.1 hrs (1520 nmi) of surveys in the PMRF region and saw a total of nine sightings (Table 1). With the exception of one sighting of pilot whales, all sightings were of smaller odontocete species (i.e., dolphins) (Table 2). The three species positively identified (spotted and spinner dolphins and pilot whales) are ubiquitous throughout the Hawaiian Islands (Figure 7; Mobley et al. 2000). The nine sightings result in a sighting rate of .006 sightings/km of linear effort.

Preliminary analysis of acoustic data from the BARSTUR and BSURE hydrophones (by Steve Martin of SPAWAR Systems Center, San Diego) recorded during periods overlapping with PMRF (reported here) and NPAL aerial surveys (see Mobley, 2003) showed a correlation between numbers of acoustic and visual detections (Figure 3). The acoustic detections consisted primarily of chorusing humpback whales with some sperm whale clicks (Martin and Mobley, 2003). These results are similar to those reported by Au et al. (2000) who showed correlations of overall sound pressure levels of chorusing humpbacks with numbers of humpbacks seen during aerial surveys.

Table 1. Summary of PMRF Surveys

Survey No.	Date	Start	Stop	No. Sightings	Mean Seastate
1	7/12/02	10:21	11:54	2	3.06
2	7/26/02	11:15	12:43	0	4.11
3	8/16/02	10:11	11:36	0	3.19
4	8/30/02	10:08	11:43	1	3.21
5	9/15/02	10:23	12:04	3	3.33
6	9/29/02	10:51	12:19	0	3.63
7	10/11/02	10:28	11:58	0	3.48
8	10/28/02	10:00	11:28	1	3.60
9	11/11/02	10:42	12:16	2	4.11
10	11/17/02	10:25	11:50	0	4.22
TOTALS:			15.1 hrs	9	Overall: 3.59

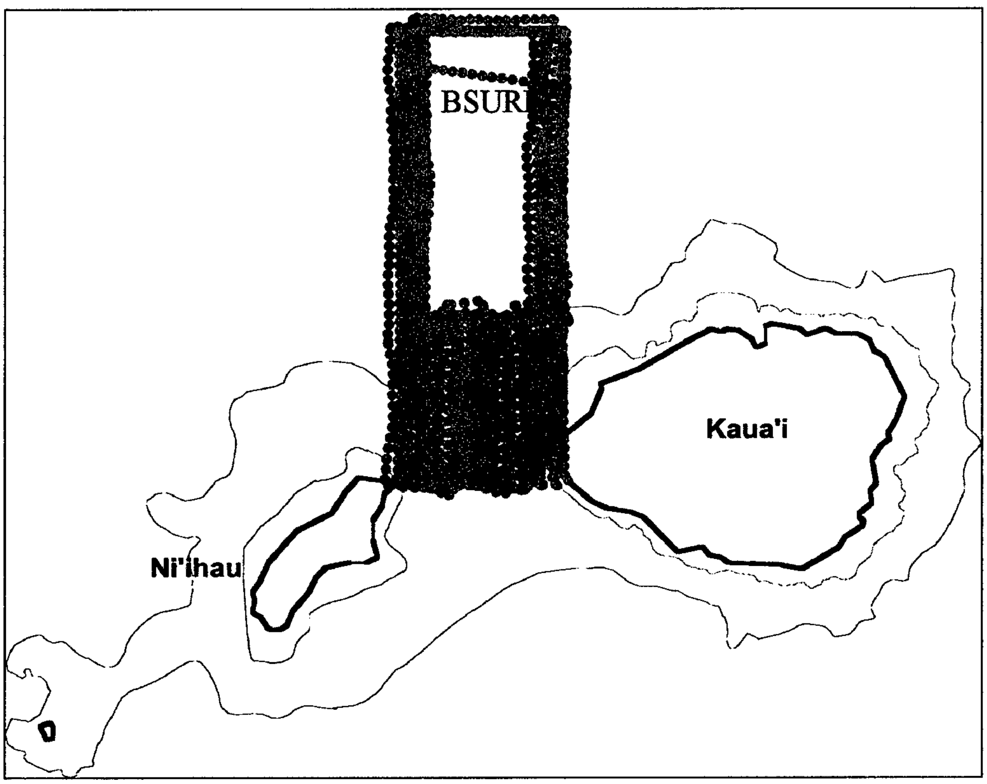

Figure 1. 2002 PMRF Survey Effort. Ten surveys were flown over the BARSTUR and BSURE hydrophone ranges during the period Jul 12 to Nov 17, 2002. Inner and outer bathymetry lines indicate 100 and 1000 fathom contours, respectively.

Table 2 . PMRF Range—Summary of Species Sightings:

Species	No. Sightings	No. Indiv.
Spotted dolphins (*Stenella attenuata*)	2	17
Spinner dolphins (*Stenella longirostris*)	1	30
Short-finned pilot whales (*Globicephala macrorhynchus*)	1	20
Unidentified dolphins	5	73
TOTAL:	**9**	

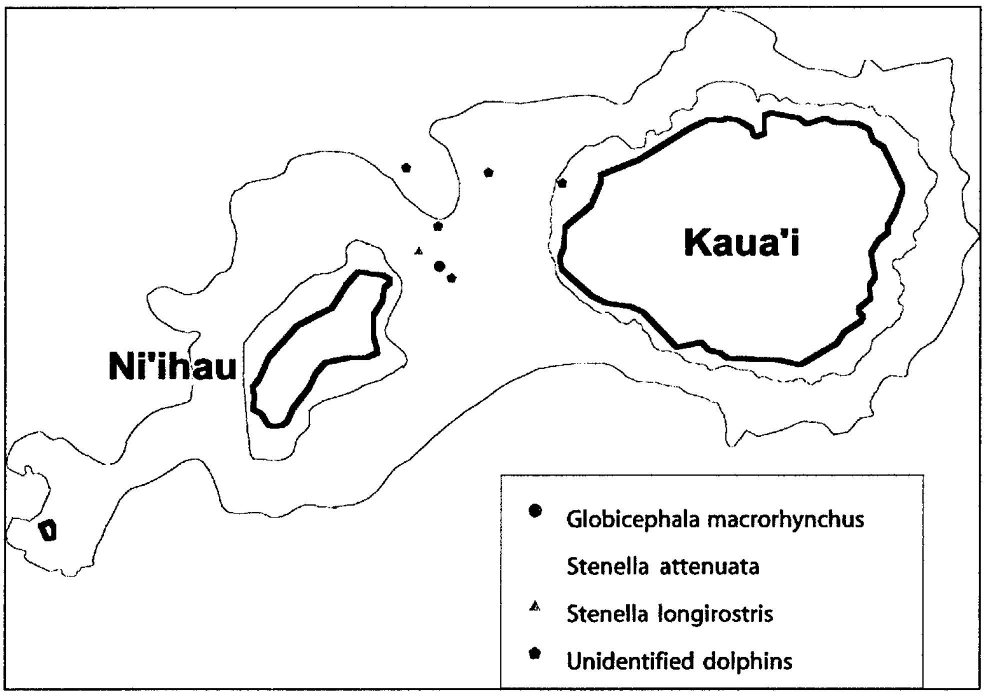

Figure 2. 2002 PMRF Sightings. A total of nine sightings were recorded during the 10 surveys, involving three confirmed species. Inner bathymetry contour is 100 fathoms; outer contour is 1000 fathoms.

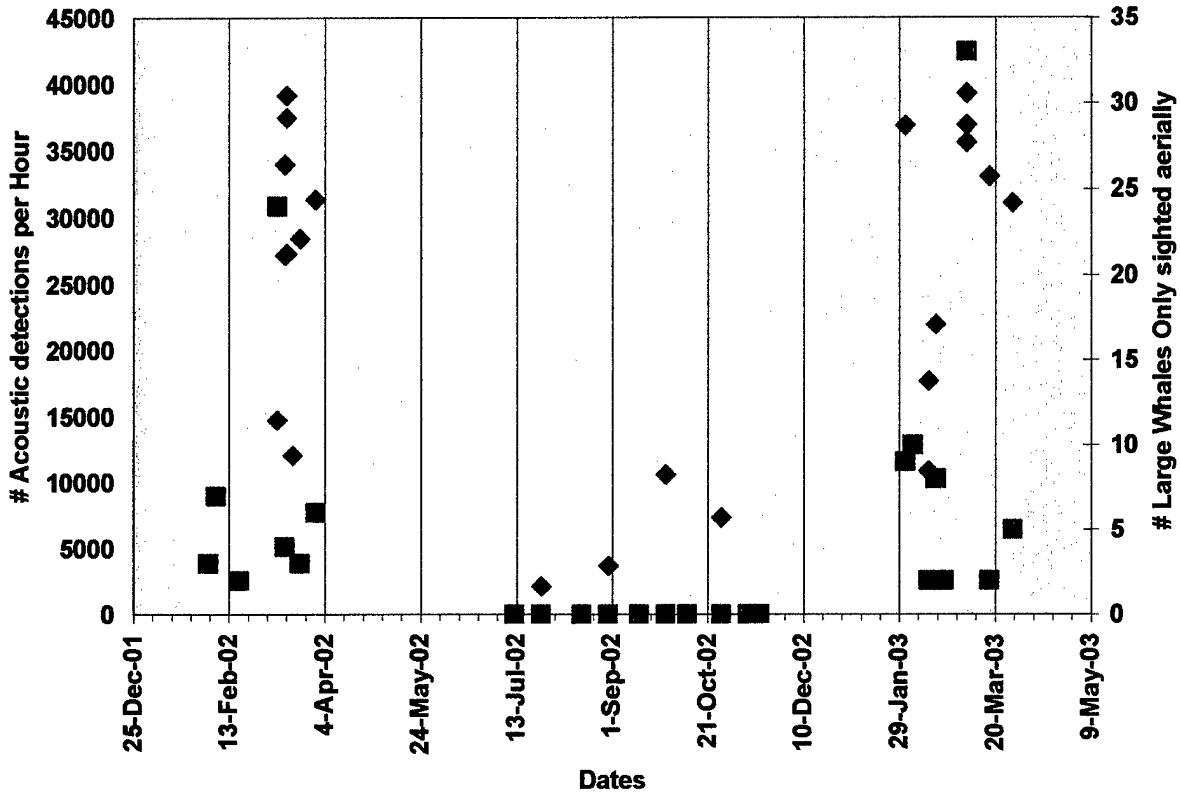

Figure 3. Correlation of visual and acoustic sightings for PMRF range. Visual detections of sperm and humpback whales (red squares) from the PMRF surveys (Jul – Nov 02) and NPAL surveys (Feb – Mar 02 and Feb – Mar 03) tended to correlate with acoustic detections (blue diamonds) from the BARSTUR and BSURE range hydrophones (Figure from Martin and Mobley, 2003).

Part II. Bahamas Surveys

The Bahamas survey series focused on the Atlantic Underwater Test and Evaluation Center (AUTEC) range and the Northwest Providence Channel (NPC). The AUTEC range consists of a rectangular array of bottom-mounted hydrophones approximately 30 nmi long by 12 nmi wide off the east coast of Andros Island. The range overlaps the Tongue of the Ocean (TOTO), a deep-water basin approximately 110 nautical miles long and 20 nautical miles wide, varying in depth from 700-1100 fathoms (1280-2012 meters).

The mission was to identify the location, species and numbers of individuals of all marine mammals in these regions. For the AUTEC range, sightings were compared with acoustic detections by the "in-water" team located on Andros Island (PI: D. Moretti).

Table 3. Summary of Bahamas Surveys

AUTEC Range					Northwest Providence Channel (NPC)				
Survey No.	Date	Start	Stop	Mean Seastate	Survey No.	Date	Start	Stop	Mean Seastate
1	1/5/03	08:46	10:04	2.86	1	1/04/03	09:48	11:26	3.00
2	1/5/03	10:16	11:33	2.68		1/05/03	13:27	15:34	1.60
3	1/8/03	08:33	10:03	2.19	2	1/06/03	10:54	13:15	2.78
4	1/8/03	10:15	12:12	1.86			14:51	16:14	3.45
5	1/8/03	14:41	15:37	2.35	3	1/07/03	09:31	10:53	5.69
6	1/10/03	07:35	08:51	3.25		1/09/03	09:49	12:09	3.67
7	1/10/03	09:20	11:00	2.43			13:44	15:18	4.16
8	1/11/03	09:00	10:35	3.00					
		15:02	16:44	1.80		Total:	12.75 hrs		
9	1/12/03	07:32	08:48	0.92					
		09:00	11:00	1.12					
	Total:	13.36 hrs							

Method

We conducted daily aerial surveys of the AUTEC range off Andros Island and the Northwest Providence Channel (NPC) between Jan. 5-12, 2003 (see Figures 4-5 below). We flew a twin-engine Partenavia Observer at 800 ft altitude, 100 knots speed using GPS navigation. Flight personnel consisted of a pilot, a data recorder and two observers (right and left sides) for a total of four personnel. When a marine mammal sighting occurred, we orbited the sighting to determine species and composition (i.e., number of individuals). In addition to recording marine mammal sightings, we noted environmental information such as seastate, cloud cover, glare and visibility at regular intervals.

During AUTEC surveys we were generally in radio communication with the acoustic team (Moretti et al.) stationed at Andros Island. On a typical day, we flew the pre-arranged tracklines

(Fig. 4) until completed, whereupon the acoustics team would direct us to the general location of an acoustic detection for visual confirmation. On some occasions, we broke in mid-survey to do so but then returned and resumed survey effort when the acoustic tracking exercise was completed. When opportunity arose (e.g., when military operations were scheduled on AUTEC), we performed surveys of the NPC region using the same methods. At this time, there was no direction from the acoustics team and surveys were flown as long as conditions permitted.

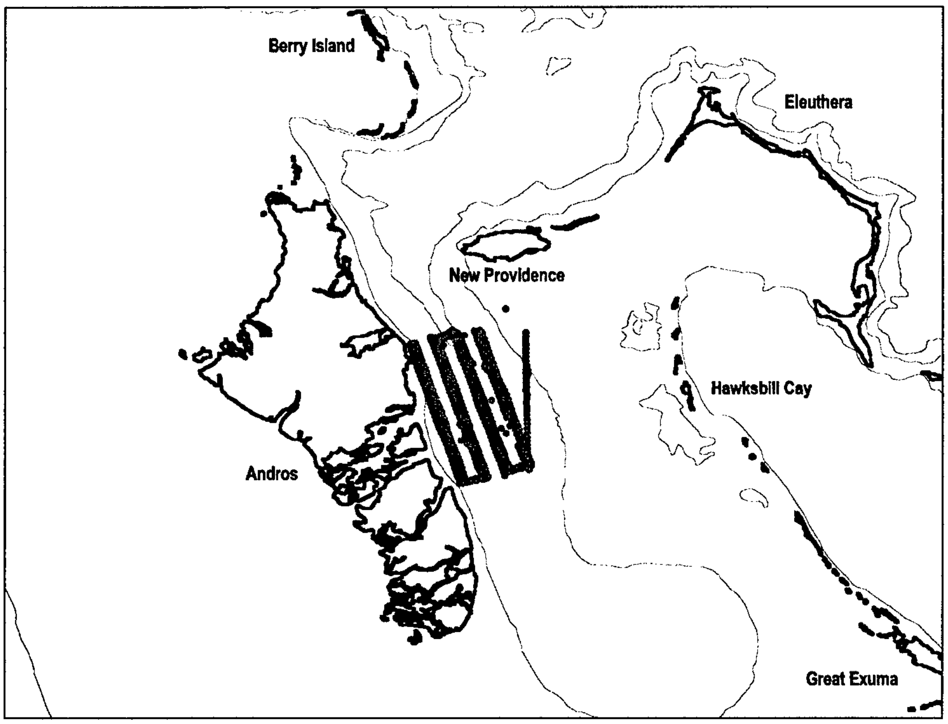

Figure 4. AUTEC survey effort. Tracklines were spaced 4 nmi apart and 30 nmi long. Inner and outer bathymetry contours correspond to the 100 and 1000 fathom lines, respectively. The Tongue of the Ocean is the deep water channel running through the AUTEC Range.

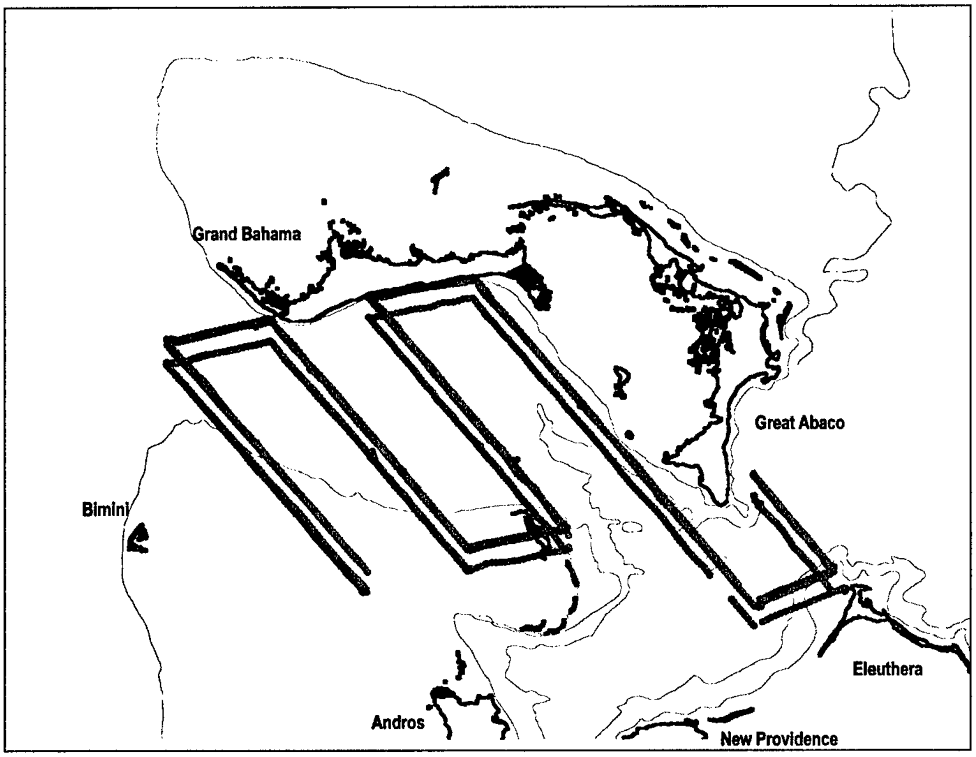

Figure 5. Northwest Providence Channel (NPC) survey effort. Transect lines were spaced 15 nautical miles (nmi) apart for a total linear effort of ca. 350 nmi. Bathymetry contour is 100 fathom limit.

Results and Discussion

Though reports exist describing the incidence of various marine mammal species in waters off the Bahamas (e.g., Balcomb and Claridge, 1997; Claridge, 1998), to our knowledge, this was the first systematic survey of waters in this region using distance sampling methods (Mobley, Deakos and Newcomer, 2003). During the eight day period, we logged a total of 26 hrs and ca. 2500 nmi of survey effort. The AUTEC region yielded thirteen sightings, consisting of five identified species (Table 4). Three of these (pygmy or dwarf sperm whales, *Kogia spp*., sperm whales, *Physeter macrocephalus*; and roughtoothed dolphins, *Steno bredanensis*) are known to be deep divers, with diets including pelagic squid (Leatherwood et al., 1988). This is consistent with the location of the AUTEC range on the southern end of the Tongue of the Ocean with maximum depth of 2400 m.

The single humpback whale sighting was unexpected; however the Bahamas lie ca. 1000 km northwest of the Silver Bank region, the primary wintering area for the North Atlantic population of humpbacks (e.g., Smith et al. 1999). It is possible that the lone whale was enroute to these wintering grounds.

The waters of the Northwest Providence Channel produced eight sightings consisting of four species. There were two sightings each of short-finned pilot whales (*Globicephala macrorhynchus*) and bottlenose dolphins (*Tursiops truncatus*) and one sighting each of melon-headed whales (*Peponocephala electra*) and sperm whales (*Physeter macrocephalus*). The majority of these sightings occurred in waters of 500-1000 m in depth. One sighting worthy of note was a pod of 55 bottlenose dolphins. Leatherwood et al. (1988) note that "the coastal form of bottlenose dolphin is rarely seen in groups of more than 50 animals (p. 175)." In contrast, the single pod of 75 melon-headed whales (*Peponocephala electra*) was not unusual since they are frequently found in large groups.

The paucity of beaked whale sightings was striking given reports of their reliable incidence in Bahamian waters (e.g., Balcomb and Claridge, 1997). For example, of the 17 cetacean species that beached themselves during the March 15-16, 2000 Bahamas stranding event, 14 were beaked whales (9 Cuvier's beaked whales, *Ziphius cavirostris*; 3 Blainville's beaked whales, *Mesoplodon densirostris*; 2 unidentified beaked whales) (NOAA / U.S. Navy, 2001). The present results include only one sighting of an unidentified beaked whale on the AUTEC range, and one off-effort sighting (south of Nassau) of a pod of five Blainville's beaked whales. The low frequency of sightings may be due more to their cryptic behavior and deep-diving practices than due to low incidence.

Table 4. Summary of AUTEC and Northwest Providence Channel (NPC) Sightings

Date	Time	Region	Species	No. Ind
1/8/2003	9:12:27	AUTEC	Pygmy or dwarf sperm whales	3
1/8/2003	9:53:03	AUTEC	Unidentified dolphins	7
1/8/2003	10:43:37	AUTEC	Unid. Beaked whale*	5
1/8/2003	11:06:08	AUTEC	Pygmy or dwarf sperm whales	1
1/8/2003	12:12:21	AUTEC	Unidentified dolphins	4
1/10/2003	11:00:17	AUTEC	Unidentified dolphins	1
1/11/2003	10:35:29	AUTEC	Striped dolphins	14
1/11/2003	16:14:48	AUTEC	Sperm whale	1
1/11/2003	16:26:00	AUTEC	Unidentified dolphins	8
1/11/2003	16:43:55	AUTEC	Unidentified dolphins	4
1/12/2003	7:46:27	AUTEC	Sperm whale	1
1/12/2003	10:18:32	AUTEC	Humpback whale	1
1/12/2003	10:59:32	AUTEC	Rough-toothed dolphins	15
1/13/2003	12:31:32	Nassau	Blainville's beaked whales[1]	5
1/5/2003	14:37:16	NPC	Sperm whales	2
1/6/2003	11:40:45	NPC	Bottlenose dolphins	22
1/6/2003	11:56:07	NPC	Short-finned pilot whales	5
1/7/2003	10:34:13	NPC	Short-finned pilot whales	1
1/9/2003	11:10:52	NPC	Bottlenose dolphins	9
1/9/2003	15:17:32	NPC	Melon-headed whales	75
1/13/2003	10:01:43	NPC	Unidentified dolphins	5
1/13/2003	10:32:39	NPC	Bottlenose dolphins	55
				22

[1] off-effort sighting

Table 5. Summary of Species Sighted—AUTEC and NPC Combined

Species	No. pods	No. Ind.
Bottlenose dolphins (*Tursiops truncatus*)	3	86
Sperm whales (*Physeter macrocephalus*)	3	4
Pygmy or dwarf sperm whales (*Kogia spp.*)	2	4
Short-finned pilot whales (*Globicephala macrorhynchus*)	2	6
Melon-headed whales (*Peponocephala electra*)	1	75
Rough-toothed dolphins (*Steno bredanensis*)	1	15
Striped dolphins (*Stenella coeruleoalba*)	1	14
Humpback whale (*Megaptera novaeangliae*)	1	1
Unid. Dolphins	6	29
Unid. Beaked whale	1	5
Blainville's beaked whale—off-effort (*M. densirostris*)	1	5
Total Sightings:	22	

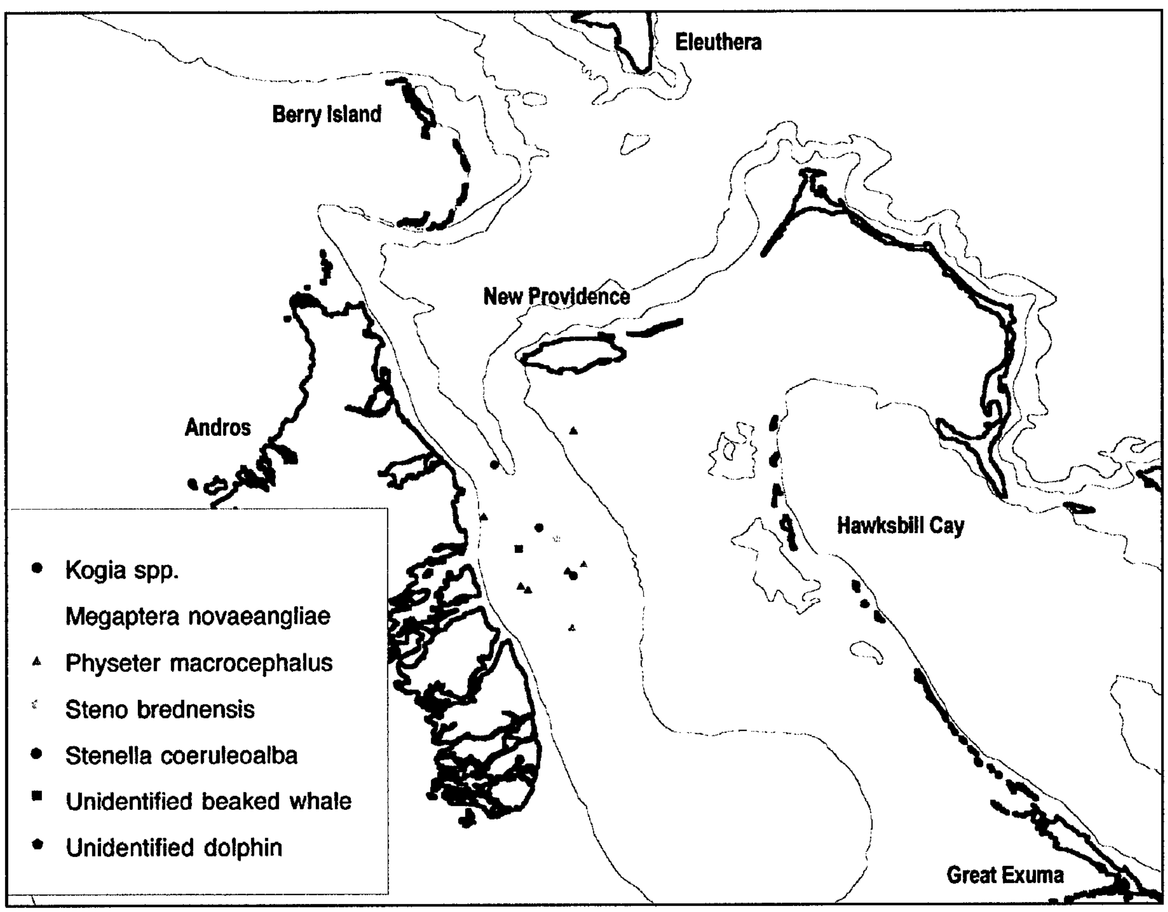

Figure 6. AUTEC Range sightings. Thirteen sightings were recorded during 13.36 hrs of surveys involving five positively identified species. Bathymetry contours correspond to 100 and 1000 fathom limits.

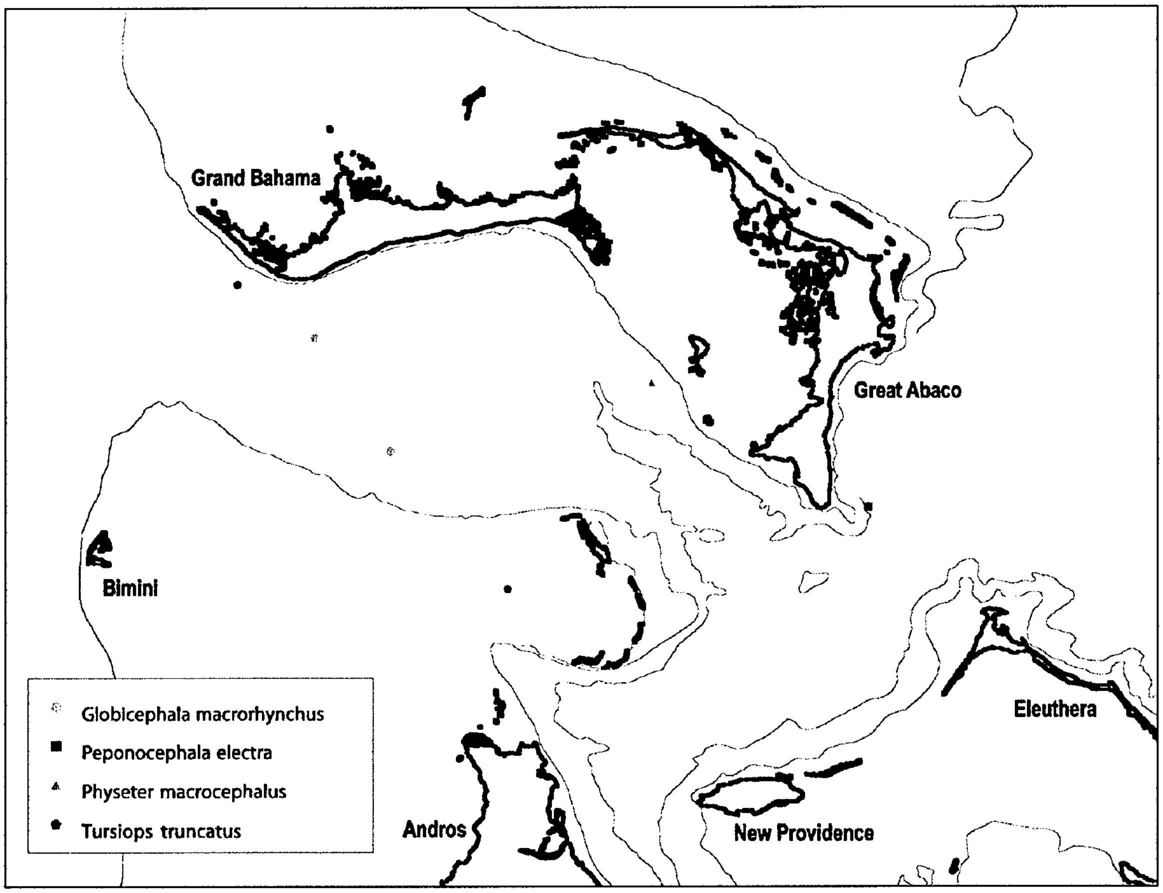

Figure 7. Northwest Providence Channel sightings. Eight sightings were recorded during 12.75 hrs of effort involving four identified species. Bathymetry contour corresponds to 100 fathom limit.

Part III. Hawaiian Island Surveys

Surveys of waters within approximately 25 nautical miles (nmi) of the major Hawaiian Islands were carried out during the period corresponding to the peak residency of wintering humpback whales (Feb-Apr) (Herman and Antinoja, 1977; Baker and Herman, 1981; Mobley, Bauer and Herman, 1999). Methods and coverage were consistent with those used during five previous years: 1993, 1995, 1998, and 2000 (Mobley et al., 2001). The mission was to identify the location, species and numbers of individuals of all marine mammals.

For humpback whales, sightings occurred in sufficient numbers to permit abundance estimation (Buckland et al., 2001). Additionally, results of 2003 were added to those of the previous years surveys to permit assessment of abundance trends across a ten-year period (1993-2003).

Method

Transect placement. The 2003 surveys followed north-south systematic lines placed 26 km apart with random legs connecting the endpoints (Figure 1). The north-south lines extended 13 km past the 1000 fathom limit which occurred at an average distance of approximately 46 km offshore. The exact placement of lines varied on each survey by using random longitudinal startpoints for the first survey of a given series.

Flight schedules. A complete survey involved coverage of all eight major islands of the Hawaiian chain, which required an average of four days. Within each year, a total of four surveys of all the island regions was completed during the period from the end of February through beginning of April (Table 1), when past surveys have shown humpback whales to be most prevalent (Herman and Antinoja, 1977; Baker and Herman, 1981; Mobley, Bauer and Herman, 1999).

Table 6. Summary of 2003 Hawaiian Island Surveys

Survey No.	Region	Date	No. Sightings	Mean Seastate	Duration (hrs)
1	K/N	2/21/03	17	3.70	4.47
	OA/PB	2/22/03	22	4.57	3.13
	FIR	2/23/03	30	4.67	4.53
	BI	2/28/03	5	4.46	3.67
2	FIR	3/4/03	55	3.91	4.39
	K/N	3/5/03	36	3.27	3.66
	OA/PB	3/6/03	34	2.53	3.15
	BI	3/7/03	71	2.78	4.16
3	FIR	3/14/03	81	2.50	4.63
	BI	3/15/03	24	1.95	4.38
	OA/PB	3/16/03	26	3.49	3.77
	K/N	3/17/03	25	2.23	5.18
4	K/N	3/29/03	16	2.45	4.19
	OA/PB	3/31/03	16	4.57	4.35
	FIR	4/2/03	24	4.05	3.19
	BI	4/5/03	7	3.46	4.03
	Total Effort: 65.75 hrs		Overall Mean: 3.38		

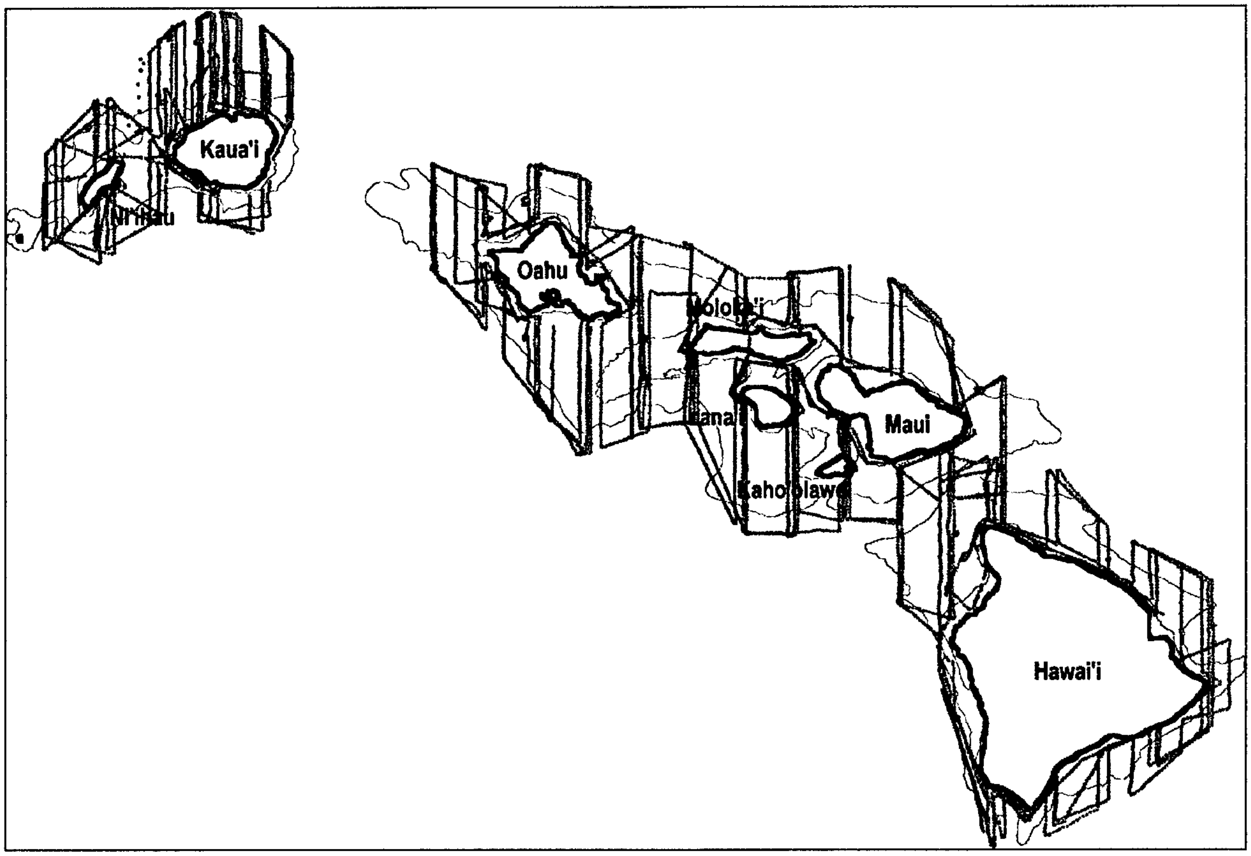

Figure 8. 2003 Hawaii Survey Effort. Red lines indicate survey effort (total = 9,030 km). Inner and outer (blue) bathymetry lines indicate 100 and 1000 fathom contours, respectively.

Results and Discussion

A. Overview

A total of 489 sightings were recorded during the 2003 surveys of the main Hawaiian Islands across 9030 km of linear effort (Table 7). Of these, 431 (88%) were of humpback whales. Sightings represented ten identified species, nine of which were odontocetes (toothed cetaceans). Species sighted during 2003 were consistent with those described in earlier survey series (Mobley et al., 2000).

Humpbacks were generally sighted in shallower waters (Figure 10) with 76% sighted in waters less than 100 fathoms (182 m). Similar to previous surveys (Baker & Herman, 1981; Mobley, Bauer and Herman, 1999) the regions of greatest whale densities were those with the greatest expanses of shallow water. In contrast, the nine odontocete species were seen throughout the range of effort (Figure 11).

Seastate and sighting probability. Increasing seastate can greatly reduce sighting probabilities of marine mammals (Buckland et al. 2001). In the case of the 2003 data for the main Hawaiian islands, sighting probability varied significantly by seastate (chi-square = 18.76, $p < .05$) with the greatest departure from expected frequency occurring beyond Beaufort seastate 3.

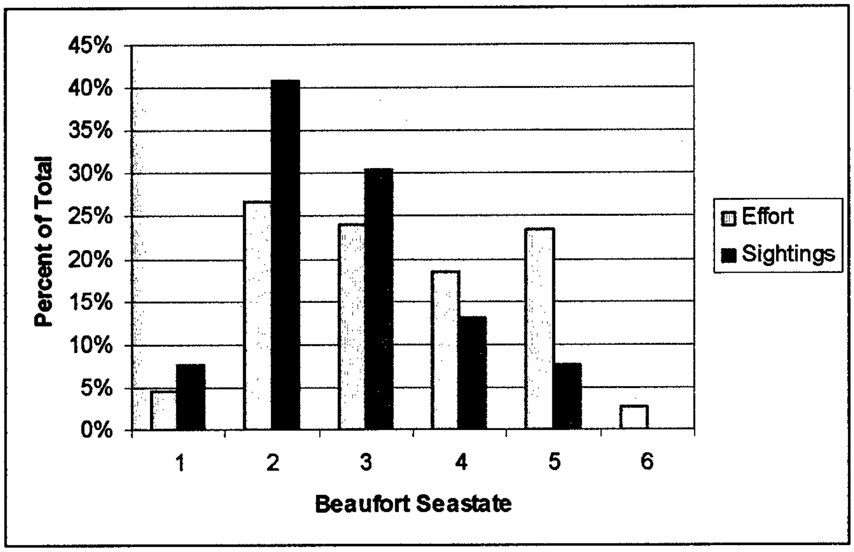

Figure 9. Hawaii Surveys: Sightings by Beaufort Seastate. Sighting probability varied significantly by seastate. The greatest departure from expected frequency of sightings occurred beyond Beaufort seastate of 3.

Table 7. Main Hawaiian Islands: 2003 Results

Species	No. Sightings	No. Indiv.
Humpback whales (*Megaptera novaeangliae*)	431	763
Bottlenose dolphins (*Tursiops truncatus*)	12	205
Spinner dolphins (*Stenella longirostris*)	7	220
Short-finned pilot whales (*Globicephala macrorhynchus*)	6	93
Spotted dolphins (*Stenella attenuata*)	4	146
Sperm whales (*Physeter macrorhynchus*)	3	5
Melon-headed whales (*Peponocephala electra*)	2	530
Rough-toothed dolphins (*Steno bredanensis*)	2	17
Dwarf or pygmy sperm whale (*Kogia spp.*)	2	10
Pygmy killer whale (*Feresa attenuata*)	2	16
Stenella species	2	35
Unidentified dolphins	11	38
Unidentified whales	2	3
Unidentified cetacean	2	3
Unidentified beaked whale	1	1
TOTAL:	489	

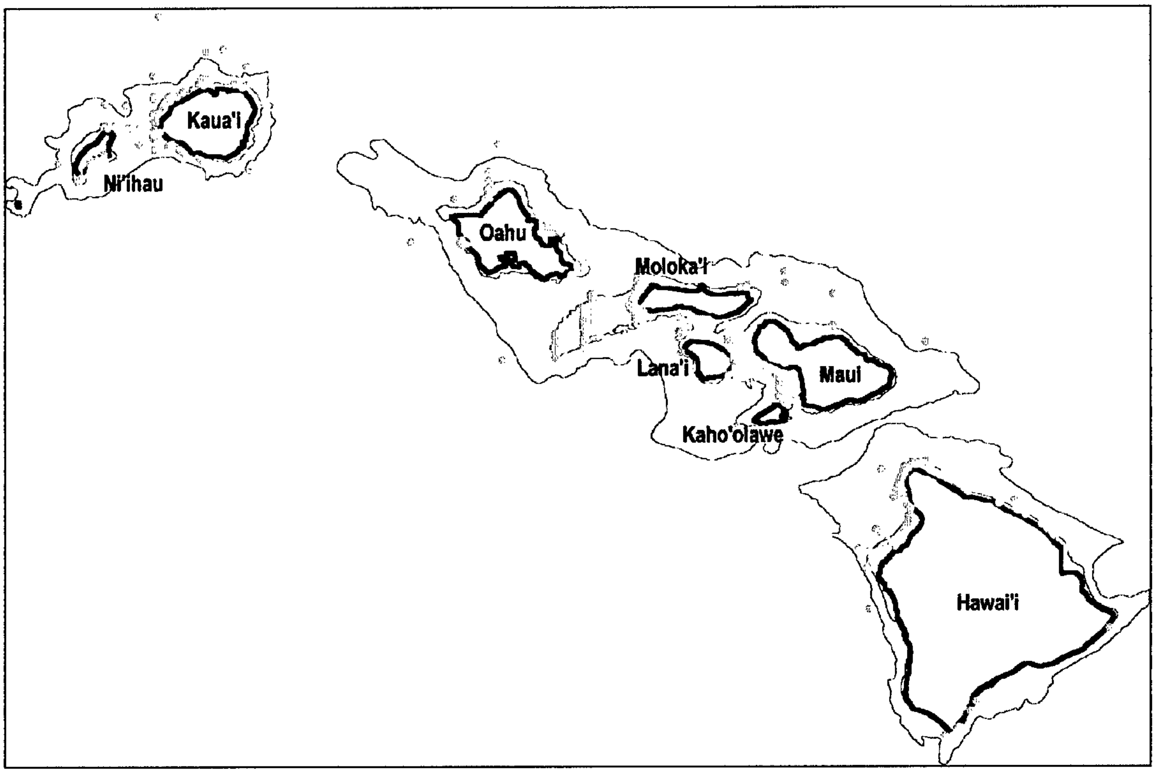

Figure 10. 2003 Humpback Sightings—Hawaii. Humpback whale sightings during 2003 surveys (blue dots). Inner and outer bathymetry lines refer to 100 and 1000 fathom contours, respectively. As shown, the majority of humpbacks were seen inside the 100-fathom limit.

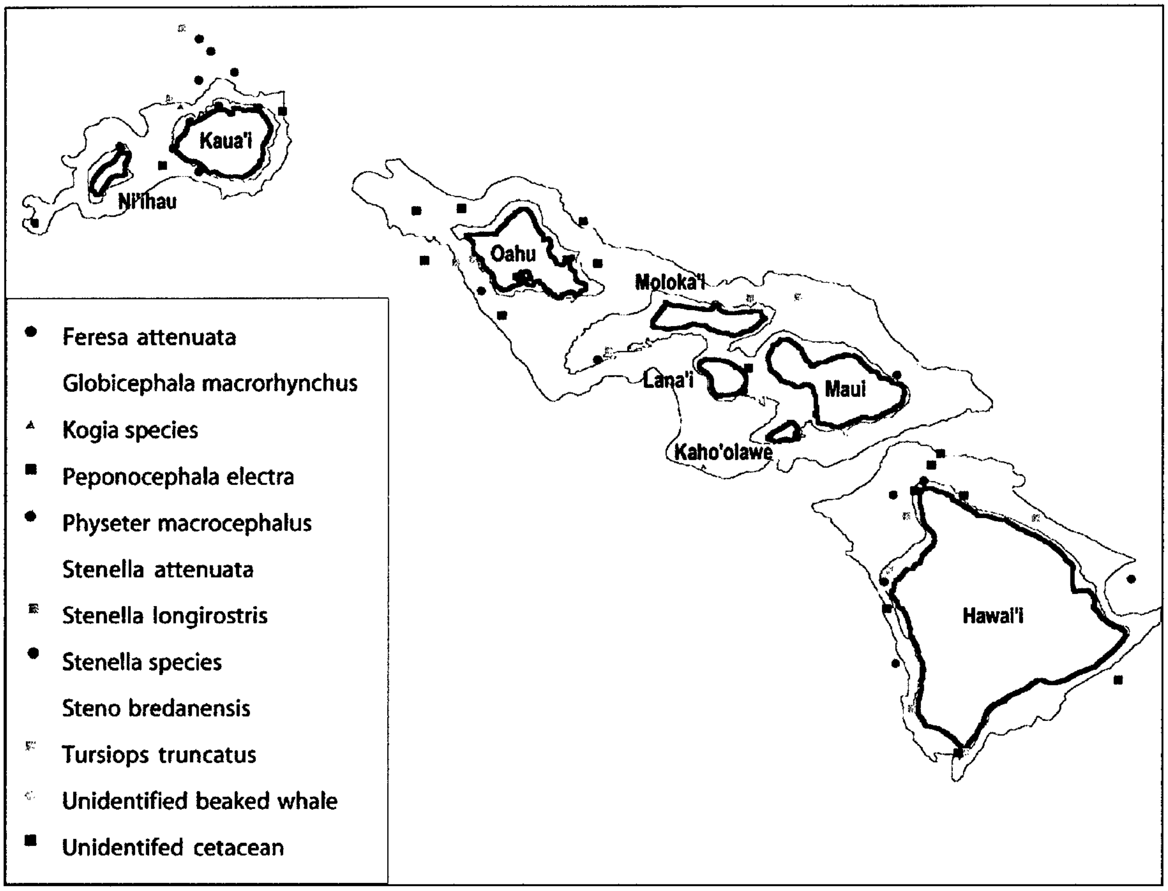

Figure 11. 2003 Odontocete Sightings—Hawaii. A total of 56 odontocete sightings were made during the 2003 surveys of waters adjoining the major Hawaiian Islands, representing nine identified species. Inner and outer bathymetry lines represent 100 and 1000 fathom contours respectively.

B. Abundance Estimation—Humpback Whales

Since distance sampling methods were used in all surveys summarized here, abundance estimation is a possible application. However, Buckland et al. (2001) recommend a minimum sample size (*n*) of at least 60-80 sightings for a given species when projecting abundance estimates. Therefore, only humpback whales in the Hawaii surveys were seen in sufficient numbers to warrant abundance estimation. Since the 2003 data were collected using methods consistent with previous years (1993, 1995, 1998 and 2000), data for all five years were combined for the following abundance analyses in order to assess trends in abundance across the ten year period (1993-2003).

General Approach. By multiplying altitude by the tangent of the sighting angle, the perpendicular distance between each sighting and the trackline was derived. Abundance estimates were then made from the dataset of sightings and perpendicular distances using the program DISTANCE (Release 3.5; Thomas et al. 1998). This program first estimates density for each species in a specified stratum using the general formula of:

$$\mathbf{D = n \cdot f(0) / (2 \cdot L)}$$

where: D = estimated density
n = number of individuals
f(0) = estimated probability density evaluated at zero perpendicular distance
L = total length of transect line

Abundance is then calculated as:

$$\mathbf{N = D \cdot A}$$

where: N = estimated abundance
D = estimated density
A = total area surveyed

Global data truncation. Sea state conditions clearly affected the sighting probability of whales beyond a Beaufort 3 (Figure 9). For this reason, survey effort and sightings made during sea states greater than 3 on the Beaufort scale were not included in the analyses. Visibility conditions were also rated on a five-point scale (excellent, good, fair, poor, unacceptable), reflecting a combination of glare and atmospheric visibility. Data gathered in fair, poor or unacceptable conditions were additionally eliminated from the data set for abundance analyses. Occasionally, only one side of the aircraft had unacceptable conditions; in these cases, sightings for that side of the aircraft were excluded and the survey effort was adjusted by dividing the number of kilometers flown in half. This adjustment affected less than 5% of the total survey effort.

Perpendicular sighting distances. Due to downward visibility limitations of the aircraft, only sightings to a maximum of 70 degrees from horizontal were possible. This created a theoretical blind area of approximately 100m on each side of the aircraft (at 245 m altitude). However, inspection of perpendicular distance data suggested that the functional blind area was about 200 m on each side of the transect line (see Figure 5 in Mobley et al. 2000). Therefore, all sightings within 200 m of the transect line were truncated prior to estimating the detection function (i.e., a left-truncated analysis was performed in DISTANCE). Truncating beyond 2km resulted in the model of best fit (based on results with lowest Akaike Information Criterion, AIC) (Figure 12). The resulting dataset was run through the DISTANCE program stratified by three depth strata (0-99, 100-1000 and >1000 fathoms) and five years (1993, 1995, 1998, 2000, 2003). This produced a total of 15 estimates of density (one for each of 15 strata). The density estimates and density variances for each year were combined weighted by area surveyed. The resultant estimates of density for each year were corrected using estimates of g(0) as described below.

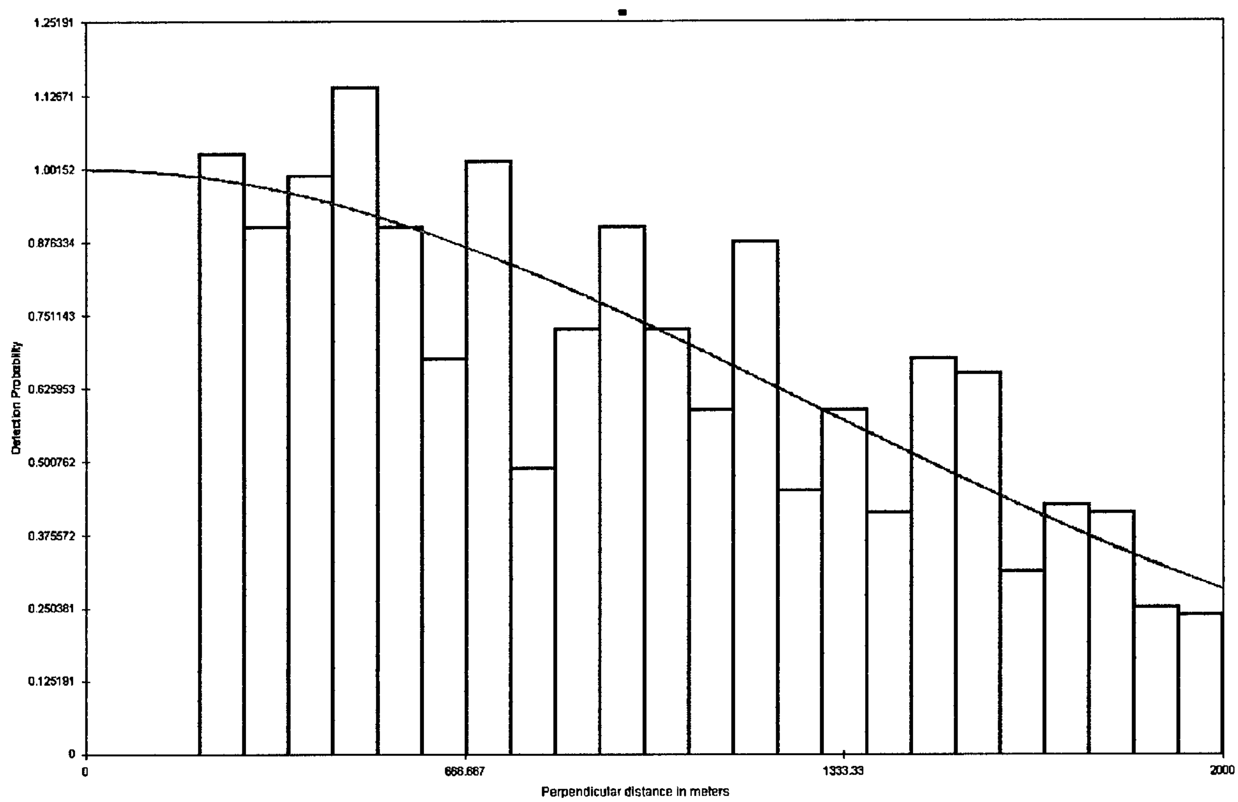

Figure 12. Perpendicular distance distribution and fitted probability density function of all humpback sightings within 2km distance of the trackline (with left truncation out to 200m) sighted during the 1993-2003 surveys.

Estimation of g(0). Distance sampling methods are based on the assumption that the probability of detecting targets on the trackline (g(0)) is unity (Buckland et al. 2001). However, since marine mammal species spend much of their time underwater, for these species g(0) < 1. Marsh and Sinclair (1989) referred to this fact as representing "availability bias." One method of correcting for availability bias when estimating abundance of marine mammal species is to use existing dive data (Hammond, 1986; Barlow, 1999). Here g(0) is calculated as the percent of time that a given species may be typically found at the surface.

Table 8 below summarizes dive data taken from unpublished shorestation observations of humpback whales in waters off west Maui and the northwest coast of the Big Island between the years 1983-88. As shown, there was considerable variance in proportion of time spent at the surface as a function of pod composition, with increasing pod size corresponding with increasing time at the surface. The overall estimate of g(0) was obtained by weighting the proportion of surface time (surface/total time) by the relative incidence of each pod type based on earlier aerial survey data (Mobley, Bauer and Herman, 1999). The overall estimate of g(0) = .26 was applied to the DISTANCE density estimates to produce corrected densities. These were in turn multiplied by the areas surveyed to produce corrected abundance estimates (Table 10).

Table 8. Summary of Respiration Data Used to Estimate g(0)

Pod Type:	Pod Size (No. adults)	N	Surface Time (min)	Total Obs Time (min)	Surface/ Total time	Percent in Population*
Pods w/out Calf:	1	148	7.256	57.545	0.126	31.3%
	2	147	8.254	50.661	0.163	28.0%
	3	35	16.740	47.454	0.353	9.5%
	4+	14	28.533	51.032	0.559	13.0%
Pods w/ Calf:	1	48	17.802	62.503	0.285	6.5%
	2	35	22.469	61.479	0.365	7.6%
	3+	13	29.808	54.319	0.549	4.1%
	Total:	440		**Estimated g(0):**	**0.26**	
				CV:	**5.7%**	

* Data from Table 1 of Mobley, Bauer & Herman 1999 based on earlier aerial survey data (1977-80 and 1990) when majority of pods were orbited to verify composition.

Truncation results. A total of 2,432 sightings of humpback whales were made during the five years surveyed (1993-2003) consisting of a total of 4,061 individual whales. Of these, only 1,228 sightings (51% of original) were used in the analysis. The remaining 49% were omitted from analysis due to the data truncations described above. The results of DISTANCE analysis on the final dataset are shown below in Table 9.

Table 9. Summary of 1993-2003 DISTANCE Results (Uncorrected)

Model Selected	Year	No. Groups in Analysis	Mean Group Size	Density (D)	CV (%)
Half Normal	1993	247	1.77	.043	10.4%
	1995	200	1.64	.052	8.5%
	1998	404	1.64	.057	11.0%
	2000	190	1.66	.070	14.1%
	2003	187	1.65	.051	12.2%

Density Trends (1993 to 2003). The half normal model was chosen over the hazard rate and uniform models on the basis of best fit (i.e., minimum Akaike Information Criterion value). As shown in Table 3, the densities of whales from 1993 to 2000 suggest an increasing trend with 2003 showing a decline. The 1993 to 2000 results described a significant linear trend [F(1,2) =

18.72, p<.05] with an average increase of 7% per year. This estimated rate of increase is consistent with the earlier report of Calambokidis et al. (1997; Calambokidis, 1999), based on photographic mark and recapture results, which revealed a 6-8% annual increase for humpbacks in feeding grounds off the coasts of Washington, Oregon and California from the period 1988-98. Similarly, Mobley, Bauer and Herman (1999) described increases in relative abundance for Hawaiian waters based on comparisons between earlier aerial surveys (1977-80) with those conducted in 1990 using consistent methods. However, the decline in densities during 2003 represents a clear departure from this trend.

Estimates of Abundance. In order to estimate abundance, the density values shown in Table 9 were multiplied by 1/g(0) or 1/.26, in this case, to produce corrected densities. The variances for both g(0) and density values were combined to derive coefficients of variation (CVs) for the corrected densities. Table 10 below summarizes these results and gives 95% confidence intervals of total abundance for each of the five years surveyed (based on averaged depth strata areas). These results are shown graphically in Figure 13.

Based on these results, numbers of humpback whales peaked during 2000 with an estimated abundance of 4,615. If the increasing density trend described above had continued, we would have expected approximately 5,275 whales by 2003. However, the current estimate of 3,558 is a full 33% below that estimate. It is not clear whether this represents a reliable downturn in abundance, or whether this was simply an anomalous estimate. More surveys are needed to determine the robustness of this trend.

Table 10. Summary of Corrected Abundance Results

						95% Confidence Interval	
Year	g(0)	CV g(0) %	Corrected Density (DC)	CV (DC) %	Corrected N	Min	Max
1993	.2601	5.7%	.1656	11.9%	2,815	2,155	3,474
1995			.2002	10.2%	3,570	2,857	4,283
1998			.2176	12.4%	3,946	2,988	4,905
2000			.2694	15.2%	4,615	3,244	5,986
2003			.1959	13.5%	3,558	2,927	4,189

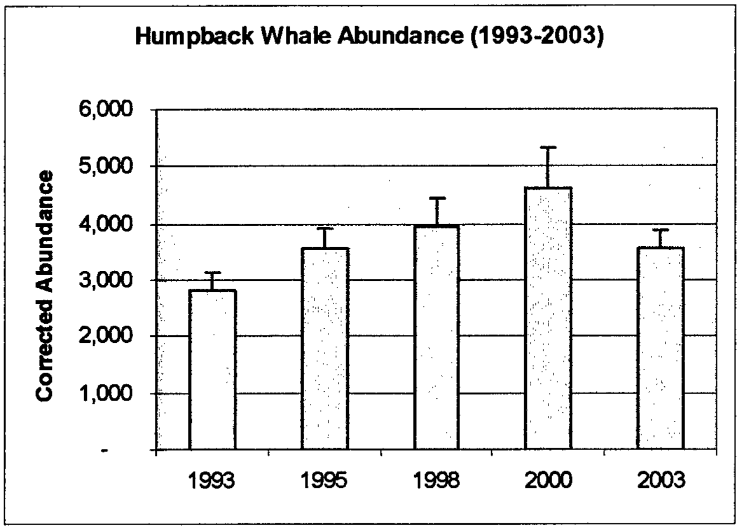

Figure 13. Humpback whale abundance estimates based on corrected densities for 1993-2003 survey results (vertical bars show standard errors).

Sources of bias. There are two potential sources of bias inherent in the data presented here. One results from the fact that sightings directly underneath the plane were not included in the analysis due to downward visibility limitations of the aircraft. This means that the sighting probabilities of animals on the trackline had to be estimated based on the probability density function from 200 m out to 5 km. If the resultant f(0) (i.e., probability density estimate at zero distance from trackline) is not accurate, then the estimates of abundance will be affected. However, since the estimated f(0) value was the same for all years studied, the relative changes in density (i.e., abundance trends) are not affected.

The second potential source of bias results from the residency rates of the animals themselves. Recent analyses of photographic recapture rates for humpbacks wintering in waters off W. Maui and the Big Island showed that 67% of whales for which resights were available (N=1,295) were seen over intervals of two weeks or less (Craig, 2000). This suggests that humpbacks are staying in a given area for relatively short periods of time and then moving elsewhere (cf. Mate, Gisiner and Mobley, 1998). They may be moving on to other islands in the Hawaiian chain, or they may be heading back to higher latitudes to feed. If the latter is occurring, then the estimates of abundance presented here are biased downward. However, again, the relative changes in abundance across years would not be affected by this pattern.

In Memorium

We would like to dedicate this report (and all subsequent reports arising from this research) to the memory of Michael W. Newcomer, one of the observers on the Bahamas project, who was killed in a survey plane crash just two weeks after finishing the Bahamas work reported here (on Jan. 26, 2003). It was an honor to have worked with him.

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