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by

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CETACEAN ABUNDANCE IN HAWAIIAN WATERS DURING SUMMER/FALL OF 2002

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ABSTRACT

The abundance of cetaceans is estimated for the U.S. Exclusive Economic Zone (EEZ) around the Hawaiian Islands based on a survey in August-November 2002. Two NOAA research vessels were used for this line-transect survey. Sighting detection functions were estimated from this and other NOAA research surveys from 1986 to 2002 using a new, multiple-covariate approach. Twenty four species were seen on this survey, including two species (Fraser's dolphin - *Lagenodelphis hosei* and sei whale - *Balaenoptera borealis*) that had not been previously documented to occur in Hawaiian waters. The most abundant large whales were sperm whales (*Physeter macrocephalus*) and Bryde's whales (*Balaenoptera edeni*). The most abundant delphinids were rough-toothed dolphins (*Steno bredanensis*) and Fraser's dolphins (*Lagenodelphis hosei*). Dwarf and pygmy sperm whales (*Kogia simus* and *K. breviceps*) and Cuvier's beaked whales (*Ziphius cavirostris*) were estimated to be quite abundant. Some of the migratory baleen whales (fin whales - *Balaenoptera physalus*, sei whales, minke whales - *B. acutorostrata*, and humpback whales - *Megaptera novaeangliae*) were seen only late in the survey. Abundance could be estimated for 21 cetacean species, but the estimated abundances of migrating whales do not correspond to their period of highest abundance in this area. The overall density of cetaceans was low in the study area, especially for delphinids. The precision of density and abundance estimates was generally low for all species due to the small number of sightings.

INTRODUCTION

Most prior studies of cetaceans in Hawaiian waters have concentrated on humpback whales (*Megaptera novaeangliae*) (Darling and McSweeney 1985; Baker and Herman 1987) and spinner dolphins (*Stenella longirostris*) (Norris et al. 1994). The species composition of other cetaceans in Hawaiian waters was described by Shallenberger (1981) and Leatherwood et al. (1982). These researchers found 21 cetacean species in Hawaiian waters plus unconfirmed sightings of three other species. Blue whales (*Balaenoptera musculus*) can be added to this species list based on vocalizations heard seasonally on a hydrophone off of Oahu (Thompson and Friedl 1982).

There is little quantitative information on the abundance of cetaceans around Hawaii. Mark-recapture methods applied to photo-identification data have been used to estimate the abundance of humpback whales around the main Hawaiian Islands (Baker and Herman 1987; Calambokidis et al. 1997; Cerchio 1998) and spinner dolphin around the island of Hawaii (Östman 1994). Aerial line-transect surveys were used to estimate the abundance of these two species plus 11 other species within 25 nmi of the main Hawaiian Islands during the months of February to April (Mobley et al. 2000, Mobley 2001). The abundance of Hawaiian cetaceans has never been estimated for the summer/fall season nor for the entire U.S. Exclusive Economic Zone (EEZ) waters surrounding Hawaii.

In this paper, I describe the results of a summer/fall 2002 ship survey of cetacean abundance in the U.S. EEZ waters surrounding Hawaii, including all of the Northwest Hawaiian Islands. The low density of cetaceans in this area and the low number of sightings posed a problem for estimating some of the line-transect parameters needed for abundance estimation. A method was developed that used information on detection probability from this and from prior surveys which used the same ships and line-transect methods in other study areas. A multiple-covariate line-transect model accounted for differing sighting conditions in the Hawaii study area compared to these previously surveyed areas. Using this approach, abundance is estimated for 21 species of cetacean.

METHODS

Field Methods

A survey of cetaceans in Hawaiian waters was conducted in summer/fall of 2002 aboard two National Oceanographic and Atmospheric Administration (NOAA) research vessels[1]. The *R/V David Starr Jordan* surveyed in Hawaiian waters from 06 August to 27 November and the *R/V McArthur* surveyed in Hawaiian waters from 19 October to 25 November. The study area was defined as the U.S. EEZ (Fig. 1). To avoid surveying at right angles to the dominant swells (generated by the NE to Easterly trade winds), the survey was designed with a series of parallel transect lines oriented in a WNW-ESE direction (Fig. 1). The location of a baseline was selected by choosing a random latitude along a chosen longitude, and the other transect lines were parallel to this baseline and were spaced 85 km apart. Because the ships returned frequently to Honolulu or Hilo to refuel, a higher density survey stratum was established within approximately 140 km of the Main Hawaiian Islands by adding transect lines that were parallel to and halfway between the main set of transects. The two strata (Fig. 1) will be referred to as the "Main Island stratum" and "Outer EEZ stratum".

Visual line-transect survey methods (Buckland et al. 2001) were fundamentally the same as have been used on Southwest Fisheries Science Center (SWFSC) surveys since 1982 (Wade and Gerrodette 1993; Barlow 1995; Kinzey et al. 2000; Gerrodette and Forcada 2002). The ships traveled at 16.7 to 18.5 km/hr (9-10 kts) during surveys. Survey effort included only those times when the ship was within 9.3 km (5 nmi.) of the planned transect lines, when two observers were searching through 25X pedestal-mounted binoculars (port and starboard "big-eyes"), and when a third observer/data recorder was searching from a center position. Observers were selected on the basis of their past experience and skill on cetacean surveys, and the on-effort team always included at least one observer who was an expert in the field identification of marine mammals. Six observers on each vessel rotated among these three observer stations, with 45 minutes per station followed by

[1] A joint Cruise Report for both ships is available at http://swfsc.nmfs.noaa.gov/PRD/cruiseinformation or by writing to the author.

2 hours rest. Observations were made from the flying bridge deck of both ships at a height of approximately 10.5 m above the sea surface. Observers searched with 25X binoculars from a bearing angle of 90° on their side of the vessel to 10° on the opposite side. The center observer/data recorder searched the forward 180° using naked eyes and, occasionally, a 7X binocular. The data recorder entered data on searching effort and sightings on a computer. Effort data included time and location, a number code for the on-effort observers, Beaufort sea state, swell height (in feet), wind speed, visibility (in nmi.), the presence of rain or fog within 5.5 km (3 nmi.) of the ship, and the vertical and horizontal location of the sun relative to the ship's bow (Kinzey et al. 2000).

When a marine mammal was seen by one of the three on-effort observers, the ship was typically directed to divert from the trackline towards the animals if they were within 5.5 km (3 nmi.) of the trackline. Perpendicular distance from the trackline was estimated from the initial bearing angle relative to the bow (measured to the nearest 1° using a protractor on the base of the 25X binoculars) and from the initial distance (measured using reticles in the oculars of the 25X or 7X binoculars). Typically the vessel approached the animals to within a sufficient distance and stayed sufficient time to allow the observers to reliably identify species, determine the proportion of each species present (for mixed species groups), and to estimate the group size. The data recorded for each sighting included time and location, initial bearing and distance, a code for the observer making the initial sighting, a code for the species present, and independent estimates (from each observer) of the overall group size (best, high and low estimates) and the proportion of each species present (in mixed species groups). Animals were identified to the lowest possible taxonomic category, usually species. If species could not be determined with certainty, observers recorded higher taxonomic levels, for example, ziphiid or *Kogia* spp. (see Table 1 for all taxonomic categories used on this survey). For sightings which could not be identified to species with certainty, the observers' best estimate of the species was typically included in the data with a "probable species" designation. For some species, photo-documentation and/or biopsy sampling followed after species determination and group size estimation.

A hydrophone array was towed on the *David Starr Jordan* during most daylight hours to detect vocalizing cetaceans that were missed by the visual observer team. The acoustics team worked independently of the visual team and did not notify the visual team of a detection unless it was past abeam and was clearly missed by the visual team. The ship was occasionally directed to the estimated location of an acoustic detection, particularly for sperm whale detections. Acoustic detections that were not seen by the visual team prior to diverting from the trackline are not included in analyses presented here. Acoustic data will be analyzed in a separate report.

Analytical Methods

Density and abundance for each species were estimated using a Horvitz-Thompson approach to incorporating multiple covariates into the estimation of the detection probability function (Marques 2001; Forcada 2002). Geographic stratification was used in the Hawaii study area to account for different levels of survey effort in the Main Island and Outer EEZ strata. The density D_i of a species within geographic stratum i was estimated as

$$\hat{D}_i = \frac{1}{2\, L_i} \sum_{j=1}^{n_i} \frac{\hat{f}_j(0, c_j)\;\; s_j}{g_j(0)}$$

where L_i is the length of on-effort transect lines in stratum i, $f_j(0,c_j)$ is the probability density of the detection function evaluated at zero perpendicular distance for sighting number j which has associated covariates c_j , s_j is the number of individuals of that species in each group, $g_j(0)$ is the trackline detection probability of sighting j, and n_i is the number of sightings of that species in stratum i. Only half-normal detection models were considered for estimating $f_j(0,c_j)$ because hazard-rate models have been shown to give highly variable estimates (Gerrodette and Forcada 2002). The covariates for the detection function were chosen by forward step-wise model building using an AIC_c criteria (Hurvich and Tsai 1989). The most distant 5-10% of sightings for each species were truncated to improve the fit near the origin (Buckland et al. 2001). The estimates of trackline detection probability, $g(0)$, (Table 2) were based on a variety of methods from other studies (Barlow 1995; Barlow 1999). For some species, $g(0)$ values vary with group size, thus the subscripted $g_j(0)$ in the above equation represents the value of $g(0)$ for group j with group size s_j. The density of most species was based on sightings in Beaufort sea states of 6 or less. Because they are so difficult to see, the density of dwarf and pygmy sperm whales and most beaked whales[2] were based on sightings in Beaufort sea states of 2 or less.

Because the number of sightings was so low on the 2002 Hawaii survey, data from previous SWFSC surveys in the eastern North Pacific were added to aid in estimating the detection function $f(0,c_j)$. These added data included surveys in the eastern tropical Pacific (ETP, 1986-90, 1992-93, and 1998-2000) and surveys off the US west coast (1991, 1993, 1996 and 2001) (Kinzey et al. 2000). The survey methods and the same two ships (*David Starr Jordan and McArthur*) were used for the Hawaii survey and for the majority of these previous surveys. Covariates included variables that have been shown to affect perpendicular sighting distances (Barlow et al. 2001). These covariates included *Ship* (*Jordan, McArthur,* or "other"), Beaufort sea state (*Beauf*, treated as a continuous variable), total school size (*TotSS,* including all species in present in a group), the natural logarithm of total school size (*LnTotSS*), visibility in nautical miles (*Vis*, treated as a continuous variable), the presence of glare on the trackline (*Glare*, treated as a logical variable), presence of rain or fog obscuring a portion of the forward field-of-view within 5.5 km (3 nmi.) of the ship (*Rain/Fog*, treated as a logical variable), and geographic area (*Geo*, coded as ETP, WestCoast, or Hawaii)[3]. Information on visibility was not collected prior to 1991, so most of the models were based on data collected from 1991-2002. For some species, the number of sightings was insufficient to reliably estimate the detection function with these data, and in those cases models were based on data from 1986-2002, and the variable *Vis* was excluded from consideration. In several cases, species were pooled to aid in estimating detection functions, and, in those cases, *Species* was evaluated for inclusion as a categorical covariate to account for real differences among those species.

Group size, *s*, was estimated as the bias-corrected geometric mean of the "best" independent estimates from each observer who made an estimate. Using a direct calibration from aerial photographic estimates of group size, Gerrodette et al. (2002) found that, on average, observers underestimated group size. Aerial photographic estimates of group size were not available to

[2]Longman's beaked whale (*Indopacetus pacificus*) was not included with the other beaked whales because this species has a distinct blow and is much more conspicuous than smaller beaked whale species.

[3] See Barlow et al. (2001) for a more complete description of these covariates.

calibrate observers for the Hawaii survey. Therefore, we corrected individual estimates of group size by dividing by 0.86, the mean correction factor from 52 observers that were calibrated by Gerrodette et al. (2002). The observers' designations of "probable species" were used in place of higher taxonomic categories in cases where species could not be determined with certainty.

The overall estimate of abundance, *N*, for each species was estimated as the sum of the densities times the areas within each geographic stratum, *i* :

$$\hat{N} = \sum_{i=1}^{2} A_i \ D_i$$

The surface area of water in the study areas, A_i , were 212,892 km^2 for the Main Island stratum and 2,240,0024 km^2 for the Outer EEZ stratum. The coefficients of variation of estimates of abundance and density were assumed to be independent and were therefore estimated as the square root of the sum of the squared coefficients of variation of the factors that contribute to uncertainty:

$$CV(\hat{N}) = \sqrt{CV^2(\frac{nS}{L}) + CV^2(f(0)) + CV^2(g(0))}$$

The coefficient of variation for the encounter rate for individuals, $\frac{nS}{L}$, was estimated by dividing all Hawaiian transects into consecutive 150 km segments and by empirically estimating the variance in encounter rates among segments . The coefficient of variation of the detection function, f(0), was estimated using the Fisher information matrix method (Buckland et al. 2001) based on derivatives that were estimated by finite difference. The coefficient of variation of the trackline detection probability, *g(0)*, was estimated from prior studies (Barlow 1995; Barlow 1999).

RESULTS

The survey covered a total of approximately 17,050 km in conditions of Beaufort 6 or less; 3,550 km of effort were in the Main Island stratum, and 13,500 km were in the Outer EEZ stratum. This effort covered each stratum fairly uniformly (Fig. 1), with a higher density of coverage in the Main Island stratum. Conditions during this survey were, on average, quite windy. Only 1,410 km of survey effort were in what are considered calm conditions (Beaufort 2 or less). The survey effort in Beaufort 0-2 conditions (Fig. 2) is less uniformly distributed than the overall survey effort.

There were a total of 159 on-effort sightings and 68 off-effort sightings made in the Hawaiian study area, and 24 different species were seen (see Table 1 for scientific names, Figs 3-15 for sighting locations). With the exception of the North Pacific right whale (*Eubalaena japonica*), all species that have previously been visually identified in Hawaiian waters were seen during this survey. Two previously undocumented species were seen on this survey (Fraser's dolphins and sei whales). Also, we confirmed a previous report by Shallenberger (1981) that the tropical bottlenose whale (Longman's beaked whale) is found in Hawaiian EEZ waters[4]. Four seasonally migratory baleen whale species were seen on the survey (minke whales, sei whales, fin whales, and humpback whales). Of these migratory species, fin whales were seen in September and October, but the others were only seen in November. Blue whales, which have been recorded acoustically in Hawaiian waters, were not seen. On this survey we were able to acoustically identify the "boing" as the call of a minke whale.[5] The boing is a ubiquitous sound heard and recorded frequently around Hawaii in winter (Thompson and Friedl 1982). Minke whales were previously "not considered to be part of the normal cetacean fauna" of Hawaii (Shallenberger 1981); however this acoustic link now reveals that they are much more common than previously thought.

Line Transect Modeling

Different sets of covariates were chosen as the best-fit model for different species (Table 3). Total school size (expressed as *TotSS*, *LnTotSS*, or both, to allow greater flexibility in fitting non-linear relationships) was the most frequent covariate that was entered in the line-transect models. Other frequently selected covariates included *RainFog*, *Beauf*, *Ship*, *Glare*, and *Vis*. The covariate *Geo* (which indicated a difference in detection functions between Hawaii and other study areas) entered into only two models. In general, models based on a greater number of sightings were more complex and included more covariates. The sample size for estimating multiple-covariate models was marginal (less than 40) for five species (Table 3), despite having pooled survey data that covered almost two decades and having, in some cases, pooled species. Of the five models that were based on pooling multiple species, the covariate *Species* entered into only one model (for Longman's beaked whale which was pooled with Baird's beaked whale to increase sample size).

Density and Abundance Estimation

The mean size of groups that were included in abundance estimates is given in Table 2 for each species. The average of the effective strip widths (given the covariates associated with sightings in Hawaii) are given in Table 3. The numbers of sightings and estimates of abundance and density (individuals / km^2) of species in both of the geographic strata are given in Table 4. The results show, surprisingly, that the most abundant cetaceans are rough-toothed dolphins, dwarf sperm whales, and Fraser's dolphins. The most abundant large whales are, by a large margin, sperm whales. Coefficients of variation for the pooled abundance estimates in both strata (Table 4) are generally high, as expected given the low number of sightings of most species.

DISCUSSION

The density of cetaceans in Hawaiian waters was found to be lower than in most areas that have been previously surveyed by the SWFSC. The low number of sightings posed a problem for abundance estimation. The use of data from previous surveys was helpful in estimating abundance for all species. Because of this approach, abundance estimates could be made for 21 species (Table

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[4]Note that Shallenberger (1981) referred to this as an unconfirmed report of *Hyperoodon* sp. The tropical bottlenose whale has only recently been found to be synonymous with Longman's beaked whale (Dalebout et al. 2003).

[5]Shannon Rankin, unpubl. data.

4) that were seen by observers while on established transect lines. Abundance could not be estimated for minke whales which were seen only after the ship was directed to the immediate vicinity of their acoustically localized vocalization (the boing). No abundance estimate was made for humpback whales in Hawaii because much better estimates already exist from mark-recapture methods (Calambokidis et al. 1997; Cerchio 1998) and from aerial surveys (Mobley et al. 2001) during their period of peak abundance. Abundance was also not estimated for the various categories of unidentified dolphin and unidentified whale (Table 1) if the observers were not able to narrow their "probable" identification to a single species.

Even though abundance could be estimated for most of the species known to exist in Hawaiian waters, the precision of these estimates is generally poor. Abundance estimates for six species are based on only one sighting. All abundance estimates are based on less than 25 sightings of each species in the study area. The lowest estimated coefficient of variation (for sperm whales) was 30%, and CVs for most species are much higher. Furthermore, the component of variance from parameter estimation is likely underestimated if the effect of the covariates used in the detection function differ between Hawaii and other study areas. However, the variance in encounter rates dominated the overall estimate of the CVs for all species, so this bias is probably very small.

Delphinids

The most abundant delphinid species was the rough-toothed dolphin (19,900, n=14 sightings), a species that has never before been documented to be the most common delphinid in any study area (Baird et al. 2003). Baird et al. (2003) did find rough-toothed dolphins to be the second most common delphinid off Kaua'i and Ni'ihau in Hawaii. The second most abundance cetacean from our study was Fraser's dolphins (16,800), but that estimate was based on only one sighting of a large group and has a very high CV. The next most common delphinids were striped dolphins, spotted dolphins and short-finned pilot whales. The dolphin that people most commonly associate with Hawaii is the spinner dolphin, but our study indicates that they are mostly concentrated near the Main Hawaiian Islands and are not very abundant outside our Main Island stratum (Table 4, Fig. 15). Spotted dolphins, bottlenose dolphins, and short-finned pilot whales also appeared clustered near the Main Hawaiian Islands (Figs. 3, 6, and 9) and were more abundant than spinner dolphins (Table 4). Although the false killer whale is the species that interacts most frequently with the Hawaiian longline fishery for tunas and swordfish, it was encountered only once during on-effort surveys, yielding an abundance estimate of only 268 (CV=1.08). This estimate is only somewhat higher than the estimate of 121 (CV=0.047) obtained by Mobley et al. (2001) based on 14 sightings made within 25 nmi of the main Hawaiian Islands. This may suggest that false killer whales are not very common around the Hawaiian Islands, or perhaps that their occurrence in Hawaiian waters is seasonal or concentrated primarily near the main Hawaiian Islands.

The overall density of delphinids in the Hawaiian study area was 0.03/km^2 (Table 4), which is more than an order of magnitude lower than the density estimated for one species (short beaked common dolphins, *Delphinus delphis*, 0.63/km^2) from the 2001 survey in the California study area (Barlow 2003, his Table 9). The total delphinid density for Hawaii is also far lower than that found in any of the 5^o latitude x 5^o longitude strata that Ferguson and Barlow (2001, their Table 12) estimated for the eastern tropical Pacific (range 0.11 to 2.34/km^2, excluding their strata 111 and 112 which were in the Hawaiian study area and which were comparably low in density).

Beaked Whales

The pooled density of all beaked whale species (0.0065/km^2, Table 4) is dominated by the abundance of Cuvier's beaked whales. The density estimate for Cuvier's beaked whales is close to the median value of density estimates for the ETP strata (Ferguson and Barlow 2001, their Table 9). The density estimate for Blaineville's beaked whales is towards the upper end of the range of density estimates for all *Mesoplodon* species in the ETP (Ferguson and Barlow 2001, their Table 11). In Ferguson and Barlow's (2001) density estimates, Longman's beaked whales were identified as the tropical bottlenose whale (*Indopacetus pacificus*) (their table 10).

Dwarf and Pygmy Sperm Whales

The pooled abundance of the two species of the genus *Kogia*, dwarf and pygmy sperm whales, is surprisingly larger than all but one of the dolphin species. However, the overall density (0.011/km^2) is towards the lower end of the range of density estimates of *Kogia* for 14 strata in the eastern North Pacific (0.002 to 0.050/km^2, Ferguson and Barlow 2001, their Table 8).

Large Whales

Sperm whales were, by a large margin, the most abundant large whale (7,100, n=18). Sperm whales were distributed widely throughout the study area (Fig. 10). Their density (0.003/km^2) falls within the broad range of densities seen in the eastern tropical Pacific (0.0001 to 0.015 /km^2, Ferguson and Barlow 2001, their Table 7). The estimate of sperm whale density for Hawaiian waters (0.003 / km^2) is at the lower end of the range estimated by Barlow and Taylor (1998) for the eastern temperate North Pacific (0.003-0.005/km^2), a study area that included a small part of the Hawaii study area but which was, for the most part, north and east of this study area.

Bryde's whales are the only non-migratory baleen whale found in the tropics and sub-tropics. They were the second most abundant large whale and had an overall density of 0.0002/km^2. This density is toward the lower end of the range of Bryde's whale density estimates for 5^o x 5^o areas in the ETP (0.0001 to 0.0043, Ferguson and Barlow 2001, their Table 3). However, all of the Bryde's whales in the Hawaii study area were found in the western half (Fig. 14), so their density there would be approximately twice as high as the overall average. This distribution corroborates other evidence of a discontinuity between eastern and western Pacific populations (Wade and Gerrodette 1993, their Fig. 18). All of the Bryde's whales seen on this survey are likely to belong to a western Pacific population.

Sei, fin, blue, and minke whales in Hawaii are probably part of seasonally migrating populations that feed at higher latitudes. Blue whales were not seen on our survey, and minke whales were not seen "on-effort". We have provided estimates of abundance for sei and fin whales only for the purpose of establishing some minimum estimates for their abundance. However, this survey was not during the expected period of peak abundance, and indeed these two species were seen only late in the survey. A realistic estimate of density or abundance for all four species would require a winter survey.

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Table 1. SWFSC species codes, scientific names, common names, and number of sightings of cetaceans seen on the 2002 Hawaiian survey. $\mathbf{N_{TOT}}$ is the total number of sightings (including off-effort sightings), $\mathbf{N_{EFF}}$ is the number of on-effort sightings in "acceptable" Beaufort sea states (Beauf 0-2 for *Mesoplodon* spp., *Ziphius cavirostris,* and *Kogia* spp. and Beauf 0-6 for all others), $\mathbf{N_{ABUND}}$ is the number of sightings within the truncation distance that were used for abundance estimation. Abundance was not estimated for some species categories (N/A).

SWFSC Species Code	SCIENTIFIC NAME	COMMON NAME	N_{TOT}	N_{EFF}	N_{ABUND}
2	*Stenella attenuata* (offshore)	Offshore pantropical spotted dolphin	14	8	8
13	*Stenella coeruleoalba*	Striped dolphin	15	11	11
15	*Steno bredanensis*	Rough-toothed dolphin	18	14	14
18	*Tursiops truncatus*	Bottlenose dolphin	15	9	9
21	*Grampus griseus*	Risso's dolphin	7	5	5
26	*Lagenodelphis hosei*	Fraser's dolphin	2	2	1
31	*Peponocephala electra*	Melon-headed whale	1	1	1
32	*Feresa attenuata*	Pygmy killer whale	3	2	1
33	*Pseudorca crassidens*	False killer whale	2	1	1
36	*Globicephala macrorhynchus*	Short-finned pilot whale	25	16	14
37	*Orcinus orca*	Killer whale	2	2	2
46	*Physeter macrocephalus*	Sperm whale	43	28	16
47	*Kogia breviceps*	Pygmy sperm whale	2	2	2
48	*Kogia simus*	Dwarf sperm whale	5	3	3
49	ziphiid whale	Unidentified beaked whale	3	1	1
51	*Mesoplodon* spp.	Unidentified *Mesoplodon*	4	0	N/A
59	*Mesoplodon densirostris*	Blaineville's beaked whale	3	1	1
61	*Ziphius cavirostris*	Cuvier's beaked whale	3	2	2
65	*Indopacetus pacificus*	Longman's beaked whale	1	1	1
70	*Balaenoptera* spp.	Unidentified Rorqual	2	1	N/A
71	*Balaenoptera acutorostrata*	Minke whale	1	0	N/A
72	*Balaenoptera edeni*	Bryde's whale	13	10	8
73	*Balaenoptera borealis*	Sei whale	6	4	1
74	*Balaenoptera physalus*	Fin whale	5	2	2
76	*Megaptera novaeangliae*	Humpback whale	1	1	N/A
77	unid. dolphinoid	Unidentified dolphin or porpoise	12	8	N/A
78	unid. small whale	Unidentified small whale or large dolphin	5	4	N/A
79	unid. large whale	Unidentified large baleen or sperm whale	4	2	N/A
80	*Kogia simus/breviceps*	Unidentified *Kogia* spp.	1	0	N/A
96	unid. cetacean	Unidentified cetacean	4	2	N/A
98	unid. whale	Unidentified large or small whale	4	3	N/A
102	*Stenella longirostris*	Spinner dolphin	8	5	4
177	unid. small delphinid	Unidentified small dolphin	8	3	N/A
277	unid. medium delphinid	Unidentified medium-sized dolphin	2	1	N/A
377	unid. large delphinid	Unidentified large dolphin	1	1	N/A

Table 2. Estimates of trackline detection probability, g(0), and mean group size. Values of g(0) were obtained from previous studies (see text) and, for some species, vary with group size. Mean group sizes are the geometric mean of "best" estimates from multiple observers and have not been corrected for bias. Bias-corrected group sizes used for abundance estimation can be obtained by dividing by 0.86.

Species	**g(0) Estimates for Group Size Ranges**		**Mean Group Size In Hawaii Study Area**
	1 - 20	**>20**	
offshore spotted dolphin	0.77	1.00	60.0
striped dolphin	0.77	1.00	37.3
rough-toothed dolphin	0.74	1.00	14.8
bottlenose dolphin	0.74	1.00	9.5
Risso's dolphin	0.74	1.00	15.4
Fraser's dolphin	0.77	1.00	286.3
melon-headed whale	0.74	1.00	89.2
pygmy killer whale	0.74	1.00	14.4
false killer whale	0.74	1.00	10.3
short-finned pilot whale	0.74	1.00	22.3
killer whale	0.90	0.90	6.5
sperm whale	0.87	0.87	7.8
pygmy sperm whale	0.35	0.35	1.0
dwarf sperm whale	0.35	0.35	2.3
unidentified beaked whale	0.34	0.34	1.0
Blaineville's beaked whale	0.45	0.45	2.3
Cuvier's beaked whale	0.23	0.23	2.0
Longman's beaked whale	0.96	0.96	17.8
Bryde's whale	0.90	0.90	1.5
sei whale	0.90	0.90	3.4
fin whale	0.90	0.90	2.6
spinner dolphin	0.77	1.00	29.5

Table 3. Data and parameters used for the estimation of line-transect parameters *f(0,c)* for each species based on 2002 and prior-year survey efforts. The best-fit model indicates the covariates selected for inclusion based on the AIC_C criterion (see text for description of covariates). Average effective strip widths (ESW) are the means for groups of the species encountered in the Hawaiian study area (hence, with the covariates associated with Hawaiian sightings). In some cases, sightings of other species or subspecies were included to improve the ability to fit a model given limited data.

Species	Years Used	Beaufort Sea States Used	Sample Size	Truncation Distance km	Best-Fit Model	Average ESW km	Other Species/Subspecies Included in Fitting Line-transect Model
offshore spotted dolphin	1991-2002	0 to 6	584	4.5	*LnTotSS*	2.78	
striped dolphin	1991-2002	0 to 6	716	4.5	*TotSS+Geo*	4.10	
rough-toothed dolphin	1991-2002	0 to 6	153	3.5	*TotSS+Geo+RainFog+Ship*	0.92	
bottlenose dolphin	1991-2002	0 to 6	549	4.5	*LnTotSS+Beauf+RainFog+Vis*	2.30	
Risso's dolphin	1991-2002	0 to 6	190	4.5	*TotSS+Beauf+Glare+Ship+RainFog*	2.86	
Fraser's dolphin	1986-2002	0 to 6	30	4.5	*RainFog+Glare+Ship*	1.85	
melon-headed whale	1986-2002	0 to 6	19	4.5	*null*	3.30	
pygmy killer whale	1991-2002	0 to 6	19	3.0	*Ship+Beauf*	1.90	
false killer whale	1986-2002	0 to 6	53	4.5	*TotSS+RainFog*	4.18	
short-finned pilot whale	1991-2002	0 to 6	148	5.5	*Beauf+Vis*	2.50	
killer whale	1991-2002	0 to 6	55	5.0	*Vis+LnTotSS*	4.42	
sperm whale	1991-2002	0 to 6	105	5.5	*LnTotSS+Beauf*	2.60	
pygmy sperm whale	1991-2002	0 to 2	76	2.5	*TotSS+LnTotSS*	1.14	dwarf & pygmy sperm whales
dwarf sperm whale	1991-2002	0 to 2	76	2.5	*TotSS+LnTotSS*	1.51	dwarf & pygmy sperm whales
unidentified beaked whale	1991-2002	0 to 2	46	4.0	*Null*	2.26	all *Mesoplodon* spp.
Blaineville's beaked whale	1991-2002	0 to 2	42	4.0	*TotSS+RainFog*	3.46	all *Mesoplodon* spp.
Cuvier's beaked whale	1991-2002	0 to 2	46	4.0	*RainFog+Ship+Vis*	1.98	
Longman's beaked whale	1986-2002	0 to 6	26	5.5	*Species+Ship*	2.63	Longman's and Baird's beaked whales
Bryde's whale	1991-2002	0 to 6	140	4.5	*LnTotSS*	2.92	
sei whale	1991-2002	0 to 6	8	5.0	*Glare*	1.98	
fin whale	1991-2002	0 to 6	168	5.5	*Ship+Glare+Beauf+TotSS*	3.55	
spinner dolphin	1991-2002	0 to 6	345	4.5	*LnTotSS+TotSS*	2.09	All spinner dolphin subspecies

Table 4. Numbers of sightings and estimated abundances of cetaceans in the two geographic strata of the Hawaiian study area. Overall abundances, densities, and coefficients of variation (CV) are pooled estimates from both strata. The components of CV due to parameter estimation, variations in individual encounter rates, and g(0) estimation are given separately.

Species	Main Island Stratum		Outer EEZ Stratum		Overall			CV	CV	CV
	#Sightings n	Abundance N	#Sightings n	Abundance N	Abundance N	Individuals/km2 D	CV	Parameter Estimation	Encounter Rate	g(0)
offshore spotted dolphin	6	4931	2	5329	10260	0.0042	0.41	0.035	0.38	0.14
striped dolphin	1	508	10	9877	10385	0.0042	0.48	0.031	0.46	0.14
rough-toothed dolphin	7	3860	7	16044	19904	0.0081	0.52	0.064	0.34	0.39
bottlenose dolphin	5	525	4	2738	3263	0.0013	0.60	0.033	0.45	0.39
Risso's dolphin	2	594	3	1757	2351	0.0010	0.65	0.057	0.52	0.39
Fraser's dolphin	0	0	1	16836	16836	0.0069	1.11	0.462	1.00	0.14
melon-headed whale	0	0	1	2947	2947	0.0012	1.10	0.218	1.00	0.39
pygmy killer whale	1	817	0	0	817	0.0003	1.12	0.307	1.00	0.39
false killer whale	0	0	1	268	268	0.0001	1.08	0.113	1.00	0.39
short-finned pilot whale	7	3131	7	5715	8846	0.0036	0.49	0.065	0.29	0.39
killer whale	0	0	2	430	430	0.0002	0.72	0.120	0.71	0.07
sperm whale	2	56	16	7026	7082	0.0029	0.30	0.084	0.28	0.08
pygmy sperm whale	0	0	2	7251	7251	0.0030	0.77	0.009	0.71	0.29
dwarf sperm whale	0	0	3	19172	19172	0.0078	0.66	0.089	0.59	0.29
unidentified beaked whale	1	330	0	0	330	0.0001	1.05	0.133	1.00	0.29
Blaineville's beaked whale	0	0	1	2138	2138	0.0009	0.77	0.204	0.71	0.23
Cuvier's beaked whale	0	0	2	12728	12728	0.0052	0.83	0.240	0.71	0.35
Longman's beaked whale	0	0	1	766	766	0.0003	1.05	0.226	1.00	0.23
Bryde's whale	0	0	8	493	493	0.0002	0.34	0.072	0.33	0.07
sei whale	1	77	0	0	77	0.0000	1.06	0.330	1.00	0.07
fin whale	0	0	2	174	174	0.0001	0.72	0.064	0.71	0.07
spinner dolphin	3	2036	1	768	2804	0.0011	0.66	0.049	0.64	0.14
DELPHINIDS POOLED	32	16403	39	62709	79112	0.0323				
BEAKED WHALES POOLED	1	330	4	15632	15962	0.0065				

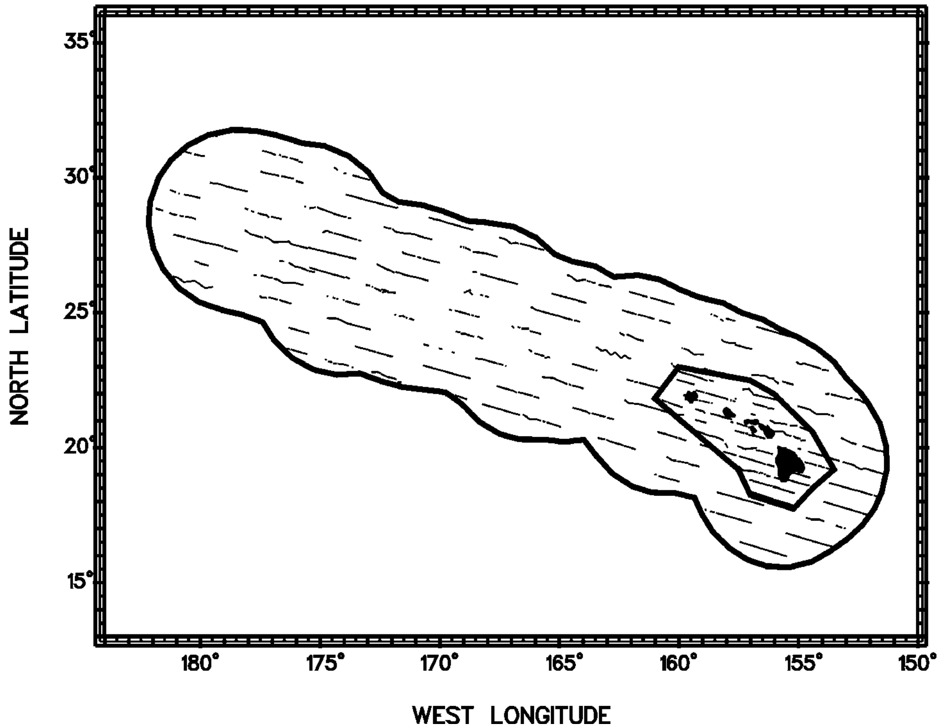

Figure 1. Search effort (fine lines) within the Hawaiian EEZ study area in Beaufort 0 to 6 conditions. Bold lines indicate the margins of the Main Island and Outer EEZ strata used for abundance estimation.

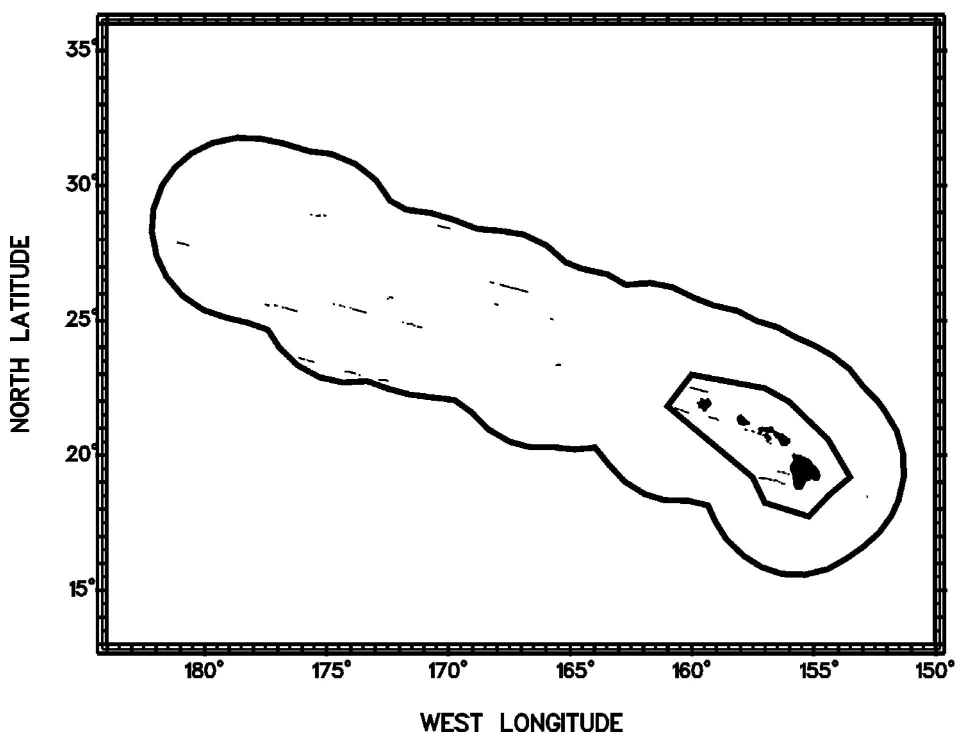

Figure 2. Search effort (fine lines) within the Hawaiian EEZ study area in Beaufort 0 to 2 conditions. Bold lines indicate the margins of the Main Island and Outer EEZ strata used for abundance estimation.

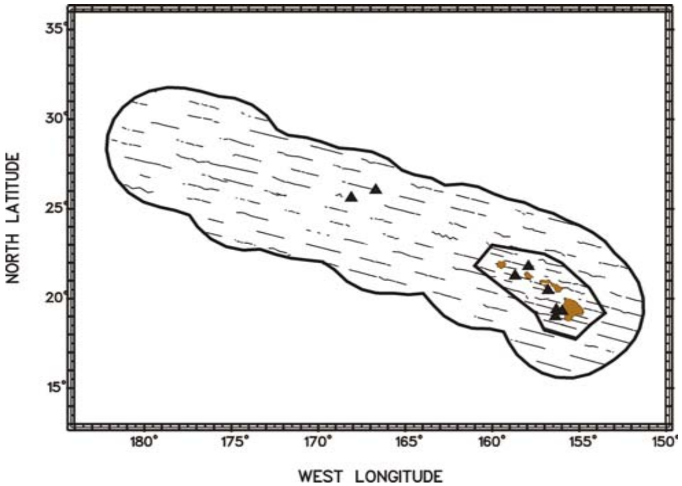

Figure 3. Locations of on-effort sightings of offshore spotted dolphins (*Stenella attenuata* •) in the Hawaiian study area.

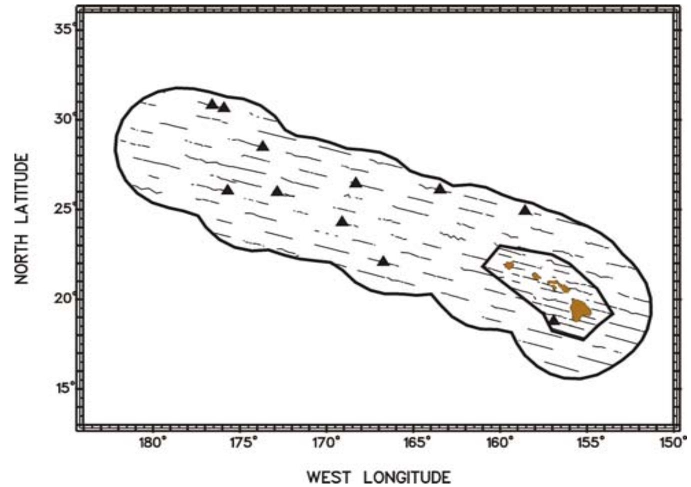

Figure 4. Locations of on-effort sightings of striped dolphins (*Stenella coeruleoalba* •) in the Hawaiian study area.

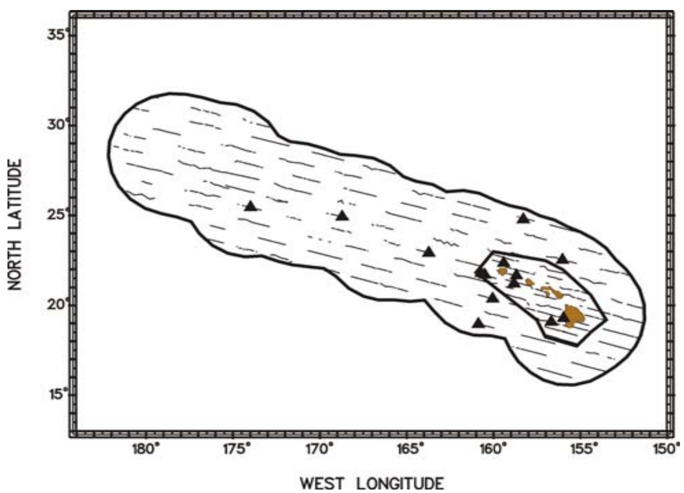

Figure 5. Locations of on-effort sightings of rough-toothed dolphins (*Steno bredanensis* •) in the Hawaiian study area.

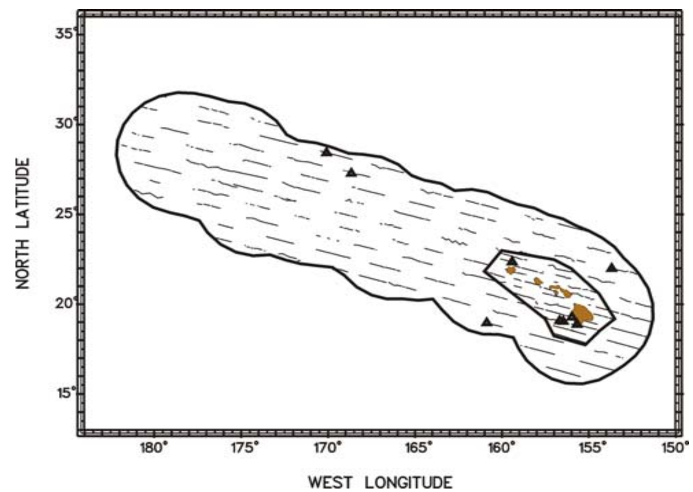

Figure 6. Locations of on-effort sightings of bottlenose dolphins (*Tursiops truncatus* •) in the Hawaiian study area.

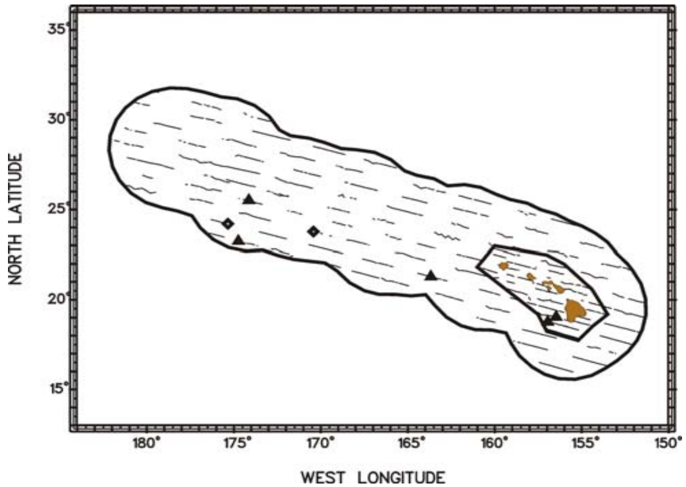

Figure 7. Locations of on-effort sightings of Risso's dolphins (*Grampus griseus* •) and Fraser's dolphin (*Lagenodelphis hosei* —) in the Hawaiian study area.

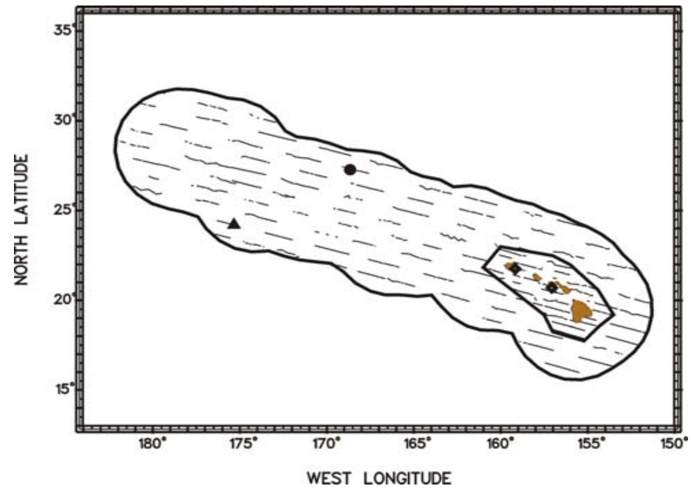

Figure 8. Locations of on-effort sightings of melon-headed whales (*Peponocephala electra* •), pygmy killer whales (*Feresa attenuata* —) , and false killer whales (*Pseudorca crassidens*) in the Hawaiian study area.

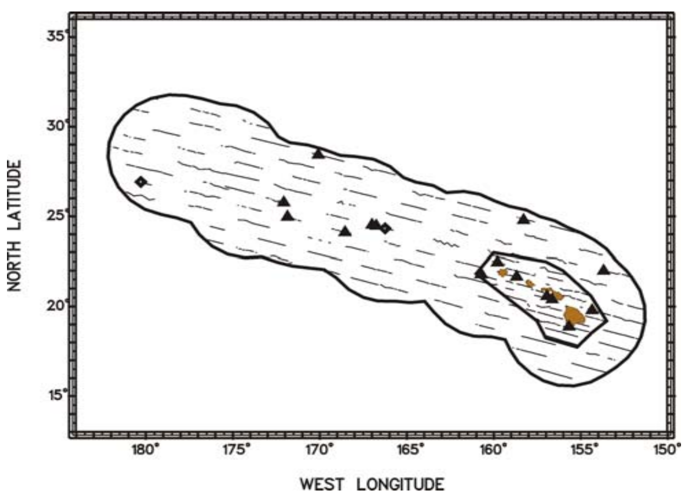

Figure 9. Locations of on-effort sightings of short-finned pilot whales (*Globicephala macrorhychus* •) and killer whales (*Orcinus orca* —) in the Hawaiian study area.

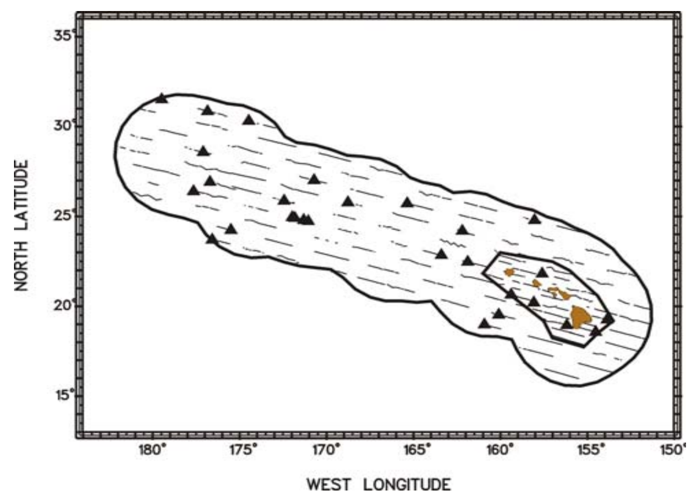

Figure 10. Locations of on-effort sightings of sperm whales (*Physeter macrocephalus* •) in the Hawaiian study area.

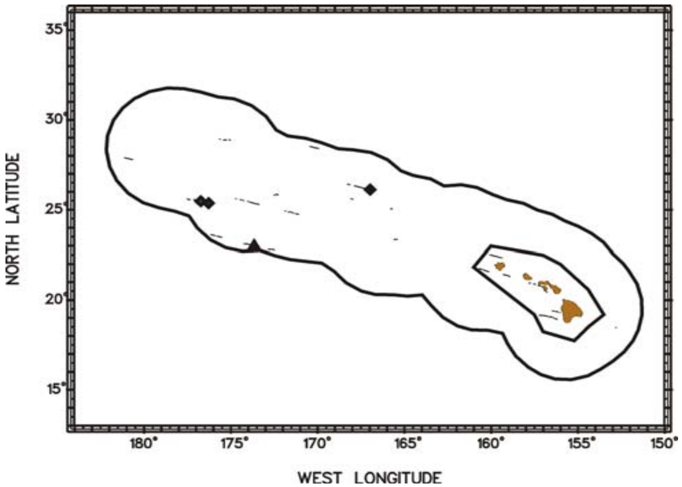

Figure 11. Locations of on-effort sightings of pygmy sperm whales (*Kogia breviceps* •) and dwarf sperm whales (*Kogia simus* —) in the Hawaiian study area.

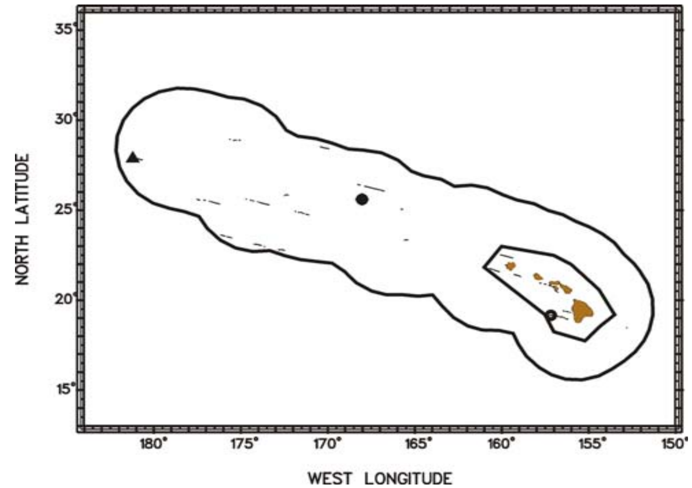

Figure 12. Locations of on-effort sightings of Blaineville's beaked whales (*Mesoplodon densirostris* •), Cuvier's beaked whales (*Ziphius cavirostris* —), and unidentified beaked whales ( ) in the Hawaiian study area.

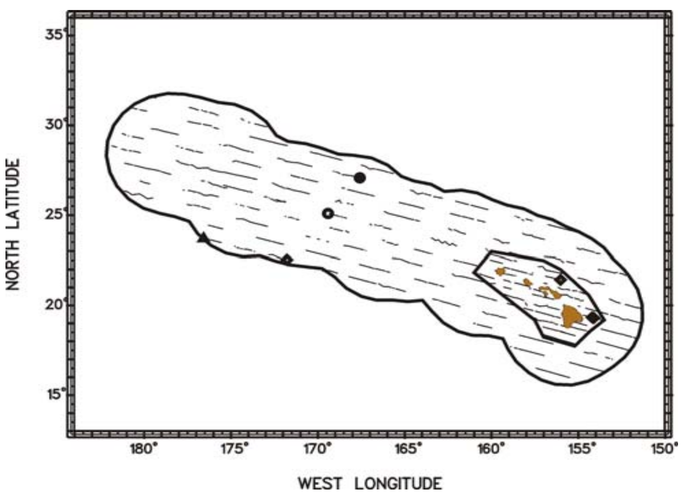

Figure 13. Locations of on-effort sightings of Longman's beaked whales (*Indopacetus pacificus* •), sei whales (*Balaenoptera borealis* —), and fin whales (*B. physalus*) in the Hawaiian study area.

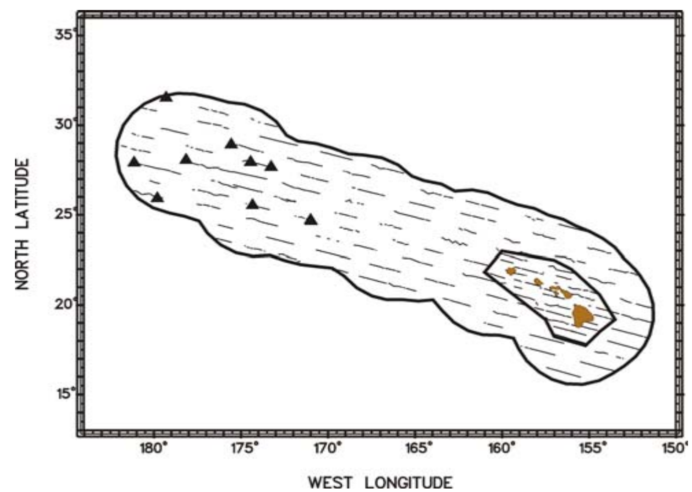

Figure 14. Locations of on-effort sightings of Bryde's whales (*Balaenoptera edeni* •) in the Hawaiian study area.

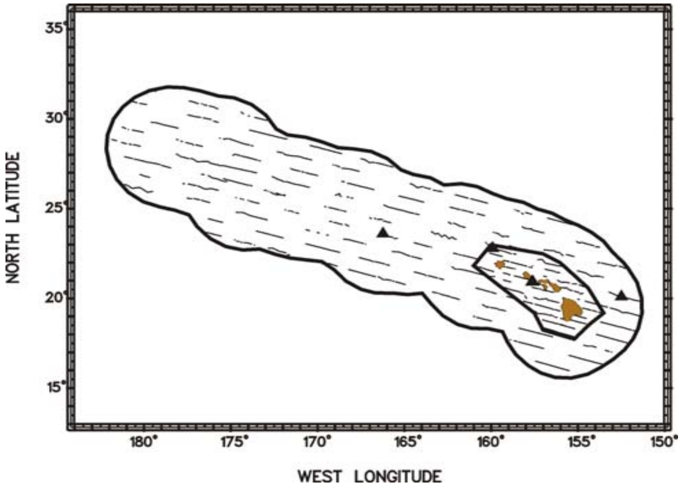

Figure 15. Locations of on-effort sightings of spinner dolphins (*Stenella longirostris* •) in the Hawaiian study area.