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FALSE KILLER WHALE ABUNDANCE AND DENSITY: PRELIMINARY ESTIMATES FOR THE PICEAS STUDY AREA SOUTH OF HAWAII AND NEW ESTIMATES FOR THE US EEZ AROUND HAWAII

by

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ABSTRACT

A visual and acoustic line-transect survey was conducted in summer and fall of 2005 to estimate the abundance of cetaceans in the U.S. Exclusive Economic Zones (EEZs) around Palmyra and Johnston Atolls and in adjacent waters south of Hawaii. The abundance and density of false killer whales (*Pseudorca crassidens*) are estimated from that survey and from a similar survey in Hawaii in 2002. A multiple-covariate line-transect analysis is used based on visual detections. Fitting the line-transect model is improved by pooling data from previous surveys and by pooling other species (pilot whales and rough-toothed dolphins) with similar sighting characteristics. Acoustic detections of false killer whales that were missed by the visual survey team are used to validate the visual estimation methods. Abundance is estimated to be 1,329 (CV=0.65) false killer whales in the Palmyra EEZ, 906 (CV=0.68) in the remainder of the 2005 study area, 484 (CV=0.93) in the Hawaii outer EEZ area, and zero in the Hawaii Main Island area. The estimated density of false killer whales in the Palmyra EEZ is higher than in areas that have been previously studied and is approximately seven times higher than in the non-Palmyra region of the 2005 study area. Density is lowest in the Hawaii EEZ area.

INTRODUCTION

False killer whales (*Pseudorca crassidens*) are found worldwide in most tropical waters (Stacey et al. 1994). Increasingly, they have been seen depredating the catch of tuna and other fish caught in long-line fisheries in the Pacific (Donoghue et al. 2002). Occasionally, false killer whales are hooked as they are taking fish from long-lines, and although some are released alive with injuries (Forney 2004), others die before they can be released (NMFS, unpubl. data). Previous assessments have shown that the number of false killer whales that die or are seriously injured in long-line sets within the U.S. Exclusive Economic Zone (EEZ) of Hawaii may not be sustainable (Carretta et al. 2006). This sort of assessment has not been possible for the U.S. EEZ surrounding Palmyra Atoll & Kingman Reef or for the U.S. EEZ of Johnston Atoll (both south of Hawaii) because estimates of false killer whale abundance were not available for those areas.

A cetacean abundance survey (PICEAS – Pacific Island Cetacean and Ecosystem Assessment Survey) was conducted in 2005 to estimate the abundance of all cetaceans in the U.S. EEZ of Palmyra Atoll and Johnston Atoll and in surrounding waters south of

Hawaii (Figure 1). This survey used both visual and acoustic line-transect survey methods. In this paper, we present preliminary estimates of false killer whale abundance from the visual component of the survey. We also review the acoustic results as they pertain to estimating the fraction of trackline animals missed by visual methods. We provide an updated estimate of false killer whales in the U.S. EEZ Hawaii based on data from the 2002 HICEAS (Hawaiian Island Cetacean and Ecosystem Assessment Survey) cruises and using improved analysis methods that were developed for this paper.

METHODS

Survey Methods

The PICEAS survey area was defined to include the U.S. EEZ areas around Palmyra Atoll & Kingman Reef (hereafter referred to as the Palmyra EEZ) and around Johnston Atoll (henceforth the Johnston EEZ) and to include the adjacent waters south of the U.S. EEZ of Hawaii (Fig. 1). A stratified design was used for the PICEAS survey. The initial design called for approximately twice the density of survey effort within the Palmyra and Johnston EEZs. A uniform series of parallel transect lines were established with reciprocal headings of NNE and SSW (Fig. 1) to quarter into the dominant swell. The initial location of the first line was determined by drawing a random number, and the remaining lines were determined by a constant spacing of 111 km (60 nmi) between lines. Within the two EEZ areas, the density of coverage was approximately doubled by placing a second series of “in between” lines midway between the primary series of lines. Based on the loss of transect time due to weather during the initial 30 days within the study area, it became obvious that we would not be able to complete the initial survey design. This design was modified to eliminate the “in between” transect lines in the Johnston Atoll EEZ. Only the Palmyra EEZ received a higher density of survey effort. For analyses, the study area was divided into two strata with different, but approximately uniform, densities of survey effort: the Palmyra EEZ (Palmyra stratum = 349,500 km^2) and all other areas pooled (non-Palmyra stratum = 1,842,600 km^2). A similar stratified design was also used on the 2002 HICEAS survey with a higher density of transects in the Hawaii Main Island stratum than in the Hawaii Outer EEZ stratum (Barlow 2006) (Fig. 2).

The 2005 PICEAS survey was conducted from the 62 m NOAA research ship *McArthur II*. Three 90-day legs of survey effort were conducted within the PICEAS study area, and the ship refueled in Honolulu between legs. Transits through the Hawaii EEZ to and from the PICEAS study area are not uniformly or randomly distributed and are not included in the analyses presented here. The 2002 HICEAS survey was conducted from two smaller NOAA ships: the 52 m *David Starr Jordan* and the 53 m *McArthur*. The basic visual and acoustic survey methods were the same on both the PICEAS and HICEAS surveys (Barlow et al. 2004, Barlow 2006), and the same visual survey methods have been used on SWFSC surveys since the early 1980s (Kinzey et al. 2000). Bearing angles to dolphin whistles were estimated using the cross-correlation algorithm in ISHMAEL software (Mellinger 2001). On the 2005 PICEAS survey, a new software tool (ROCCA – Real-time Odontocete Call Classification Algorithm) was available to determine the species of dolphin from their whistle vocalizations (Oswald

2006). During the PICEAS survey, most whistling groups of dolphin were classified using this software. Species identification by acoustics was visually verified for the subset of these groups that were seen by the visual survey team. Groups that were acoustically determined to be "probable" false killer whales were opportunistically pursued to verify species identity and (if possible) to obtain biopsy samples if they passed abeam of the ship without being seen.

Analysis Methods

False killer whale abundance and density were estimated from visual survey data using the same multiple-covariate line-transect method (Marques & Buckland 2003) that was used previously to estimate false killer whale abundance for the Hawaii EEZ (Barlow 2006). To briefly summarize, sightings were pooled from SWFSC tropical cetacean surveys (1986-2005) in order to fit the line-transect model of sighting probability as a function of distance from the transect line and the other covariates that affect the detection of cetaceans. In addition to the 2002 HICEAS and 2005 PICEAS surveys, these included 11 surveys in the eastern tropical Pacific (ETP, from 1986 to 2003). Sightings beyond 4.5 km from the trackline were excluded to improve the fit near the origin (Buckland et al. 2001). Only the half-normal model was used. The following covariates were considered for inclusion in the model: *Ship* (*Jordan, McArthur* or *McArthur II*), Beaufort sea state (*Beauf*, treated as a continuous variable), total group size (*TotGS*, including all species present in a group), the natural logarithm of total group size (*LnTotGS*), sighting method (*Bino* as either 25X binocular or other), sighting cue (*Cue* as the animal itself (dorsal fin, body, etc), a blow, or other (associated birds, splashes, etc)) the presence of glare on or near the trackline (*Glare*, treated as a logical variable), the presence of mixed species in the same group (*Mixed*, treated as a logical variable), and the presence of rain or fog obscuring a portion of the forward field-of-view (*Rain/Fog*, treated as a logical variable)[1]. To account for other possible differences in sighting distances among geographic areas, *Region* was also considered as a covariate (coded as either ETP or PICEAS/HICEAS). Categorical variables were only considered if each factor level had at least ten sightings. Covariates were added using forward step-wise model building based on the AIC_c criterion.

Geographic stratification accounted for different levels of survey effort in the Hawaii EEZ, Main Island, Palmyra and non-Palmyra strata. The density D_i of a species within geographic stratum i was estimated as

$$D_i = \frac{1}{2 \cdot L_i} \sum_{j=1}^{n_i} \frac{f(0, c_j) \cdot s_j}{g_j(0)} \qquad (1)$$

where L_i is the length of "on-effort" transect lines in stratum i,

$f(0,c_j)$ is the probability density of the detection function evaluated at zero perpendicular distance for sighting number j with 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.

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

The trackline detection probability (*g(0)*) for false killer whales was taken from the value used by Barlow (2006) for groups of large delphinids with less than 20 individuals (*g(0)*=0.76, CV=0.14). Abudance (N_i) within each stratum was estimated as the product of the density (D_i) times the geographic size of the stratum (A_i). Abundance and density estimates were corrected for bias in estimating group size by dividing by 0.86 (Gerrodette & Forcada 2005, Barlow 2006). A bootstrap with 200 iterations was used to estimate the coefficient of variation for abundance and density estimates. The sampling unit for the bootstrap sampling was a 150 km segment of consecutive search effort or roughly one survey day. We re-sampled the actual number of segments within each stratum with replacement. We used the same combination of parametric and non-parametric bootstrap as Barlow (2006) with two additions. We included both model selection and model averaging in the bootstrap, whereas Barlow (2006) used only the single best-fit model in his bootstrap.

Two slight modifications were required in fitting the line-transect parameters $f(0,c_j)$ to account for higher survey platform on the *McArthur II* (15.2 m) relative to the heights (~10.5 m) of the two ships (*David Starr Jordan* and *McArthur*) that were used on previous surveys. Effective strip width (ESW) is the inverse of *f(0)* and is relative measure of how far animals can be seen from the trackline. In analyses of the 2003 ETP survey, Gerrodette et al. (2005) found that dolphin ESWs were greater from the *McArthur II* than from the *Jordan*. However, the sample size of sightings of false killer whales alone (n = 69) is not sufficient to quantify this effect. Therefore, I pooled false killer whales with short-finned and long-finned pilot whales (*Globicephala macrocephalus* and *G. meleus*) and rough-toothed dolphins (*Steno bredanensis*) to boost the sample size for estimating this "*Ship*" effect as well as the effects of the other covariates included in the model. Both species are similar to false killer whales in that they are large, tropical delphinids and they occur in small groups. Pilot whales are larger than false killer whales, but both often have visible blows. Rough-toothed dolphins are smaller than false killer whales, typically do not have visible blow, but are like false killer whales in that they are difficult to re-sight. To prevent an inherent difference in the sightability of these other species from biasing the estimate of false killer whale abundance, another covariate (*SpeciesGroup*- either false killer whale, rough-toothed dolphin or pilot whale) was included in all potential models. The "base model" for all stepwise model building therefore included *Ship* and *SpeciesGroup*. Additional covariates were added to this model to minimize AIC_c.

Another modification in the analyses compared to Barlow (2006) was the use of model averaging (Gerrodette & Forcada 2005). Abundance was estimated from a weighted average of all line-transect models that were within 2 AIC_c units of the best-fit model. I only considered those models that were found in the process of forward step-wise model building. The values of $f(0,c_i)$ used to estimate abundance were a weighted average of all acceptable models ($\Delta AIC_c < 2$) and the weights were estimated as $\exp(-0.5\Delta AIC)$ (Burnham & Anderson 1998).

The acoustic data could not be used directly to estimate the fraction of trackline animals missed due to a number of factors. Acoustic species recognition based on whistles is not 100% accurate for any dolphin species. In her study of the effectiveness of the program ROCCA to classify dolphin whistles, Oswald (2006) found that approximately 80% of false killer whale groups were correctly classified, but that approximately 40% of pilot whale groups and 4% of spotted dolphin groups were misclassified as false killer whales. Usually, on the PICEAS survey, attempts were made to visually locate and verify groups that were classified as "possible" or "probable" false killer whales, but that was not possible if the group could not be localized. [Many of the groups that could not be acoustically localized were likely to be outside the truncation distance of 4.5 km and thus would not included in analyses.] Attempts to visually confirm acoustic detection also failed in other cases when the weather was very rough or when the animals stopped vocalizing. Although some acoustic detections were visually confirmed, we were left with a large number of acoustic detections that were "possible" or "probable" false killer whales. To help determine whether our line-transect parameters (*f(0)* and *g(0)*) for visual survey are consistent with our acoustic detections, we assumed that all acoustic detections of "confirmed", "possible" and "probable" false killer whales were really false killer whale. If all false killer whales were acoustically detected and classified in one of these three categories, this assumption will result in estimation of the maximum proportion of false killer whales missed. We estimated the fraction of total detections (acoustic and visual detections within the truncation distance) that were missed by visual observers, and we compared this fraction missed with the expected fraction missed based on our estimated line-transect parameters.

The expected fraction of animals missed within the truncation distance (4.5 km) was calculated from the estimated values of *f(0)* and *g(0)*. In the covariate line-transect approach, the "inclusion probability" represents the probability that a group that is within the truncation distance w will be seen, assuming that groups are not missed on the trackline (Marques & Buckland 2003). This inclusion probability is estimated as $1/(w \cdot f(0))$. The overall probability of seeing a group that is within the truncation distance is the product of the inclusion probability times the trackline detection probability, *g(0)*. Substituting the mean effective strip width (ESW = 1 / *f(0)*), the overall probability of missing a group within the truncation distance (Pr(*missed* | $d \leq w$)) can be estimated as:

$$\Pr(Missed \mid d \leq w) = 1 - \left[\, g(0) \cdot \frac{ESW}{w} \,\right] \qquad (2).$$

RESULTS

Visual Detections

Visual search effort on the HICEAS and PICEAS surveys covered 19,700 and 11,100 km of transects (respectively) in Beaufort sea state conditions of 6 or less within the designated study areas (Fig. 1-2). Weather was rough for much of both surveys, and there was very little survey effort in Beaufort sea states of 2 or less (Table 1). Rough seas (Beaufort 5-6) were especially prevalent in areas outside of the Palmyra and Johnston EEZs (Table 1). Several days were lost completely due to weather.

There were only seven on-effort sightings of false killer whales in the PICEAS study area (Fig 1) and one on-effort sighting in the Hawaii EEZ. [One additional sighting was classified as a "probable" false killer whale within the Palmyra EEZ but was at a perpendicular distance (8.7 km) that was outside the truncation distance for the line-transect analysis (4.5 km) and was therefore excluded from the abundance estimation.] Four of the seven PICEAS sightings of false killer whales were within the Palmyra EEZ. In addition, there were six acoustic detections of false killer whales that were confirmed visually on the PICEAS survey (Fig 3). Group sizes varied from one to ten individuals. All the group sizes were less then 20, so the trackline detection probability (g(0)) was 0.76 for all (Barlow 2006). One of the seven groups that were detected by on-effort visual observers on PICEAS and the only on-effort group on HICEAS were mixed groups of false killer whales and bottlenose dolphins, but all the other groups contained only false killer whales.

Abundance Estimation from Visual Detections

The multiple-covariate line-transect model was fit to false killer whales (n=69), rough-toothed dolphins (n=335), and pilot whales (n=432) using SWFSC sightings of both species from 1986-2005. This model was forced to include *Ship* and *SpeciesGroup* as covariates, and the remaining covariates were selected by forward step-wise model building based on minimizing AIC_c. The best-fit model also included *Bino, Beauf, Mixed, Cue* and *Glare* as covariates. Two other models had an AIC_c value within 2 units of the best-fit model (Table 2), so the final abundance was based on a weighted average of these three models. Notable, neither of the group size covariates (*TotGS* nor *LnTotGS*) was included in any of the final models (contrary to Barlow's (2006) best-fit model for false killer whales alone that included only *TotGS* as a covariate). The coefficients of the covariates in the best-fit model are given in Table 3.

Abundance was estimated to be 1,329 (CV=0.65) false killer whales in the Palmyra EEZ, 906 (CV=0.68) in the remainder of the PICEAS study area, 484 (CV=0.93) in the Hawaii outer EEZ area, and zero in the Hawaii Main Island area (Table 4). The density of false killer whales was approximately seven times higher in the Palmyra EEZ than in the non-Palmyra region and was lowest in the Hawaii areas.

Acoustic Detections

All on-effort visual detections of false killer whales on the PICEAS survey (n=8) and on the HICEAS survey (n=1) were also detected acoustically, either before they were seen or at approximately the same time they were seen. False killer whales are very acoustically active during daylight hours and there is a high probability that groups within the truncation distance of 4.5 km will be heard. One of these eight was greater than 4.5 km from the transect line.

In addition to these eight groups that were visually <u>and</u> acoustically detected, there were six additional acoustic detections that were later confirmed visually (after they had passed abeam and had been clearly missed by the visual survey team). Of these six, four were within 4.5 km of the trackline.

Finally, there were ten acoustic detections that not detected visually and were classified as "possibly" or "probably" a false killer whale based on the determinations of ROCCA software and the expert judgment of the acoustic technicians, and there was one sighting that was classified visually as an "unidentified small whale" but was identified acoustically as being a "possible" false killer whale. Eight of these eleven sightings were within the 4.5 km truncation distance, but three of these occurred when the visual observers were "off-effort" due to weather, leaving five sightings for the analysis.

On the PICEAS survey, nine "confirmed", "probable" or "possible" acoustic detections of false killer whales were within the 4.5 km truncation distance but were missed by on-effort visual observers. If we assume that all of these are false killer whales, then the total number of visual and acoustic detections with 4.5 km of the transect line is 16, and the fraction of groups missed by the visual observers is 9/16 or 0.56.

Expected Fraction of Groups Missed

Based on the mean effective strip width (ESW = 2.24) for the PICEAS study area and the estimated trackline detection probability ($g(0)$ = 0.76), the expected fraction of groups missed by visual observers within the truncation distance (w = 4.5 km) is estimated from Eq. 2 to be 0.58.

DISCUSSION

The density of false killer whales in the Palmyra EEZ (0.38 animals per 100 km^2) is the highest value that has been measured for this species on SWFSC surveys. For comparison, the overall density in the ETP study area is 0.16-0.21 per 100 km^2 (Wade & Gerrodette 1993, Ferguson & Barlow 2001) and the highest density in any ETP stratum was 0.33 per 100 km^2 north of 5º N and west of 120º W (Ferguson & Barlow 2001). In contrast, the density in the remainder of the PICEAS study area was only 0.05 per 100 km^2, a value that is lower than the average density in the ETP study area. The density estimated here for the Hawaii EEZ study area was even lower (0.02 per 100 km^2).

Barlow (2006) presented estimates of density (0.01 per 100 km^2) and abundance (N=236) for false killer whales in the Hawaii EEZ stratum that are lower than our estimates for this stratum. The primary reason for this difference is the inclusion of pilot whales and rough-toothed dolphins to greatly increase the sample size for determining which covariates to include in the line-transect model and to better quantify their coefficients. Based only on false killer whales, the best-fit model included only group size (*TotGS*) as a covariate (Barlow 2006). The one false killer whale sighting during the 2002 HICEAS survey was a relatively large group for false killer whales (n=10), so the effective strip width (ESW) estimated for that sighting was quite large (4.2 km), higher than the mean ESW for any other species (Barlow 2006). In this re-analysis based on pooling false killer whales, rough-toothed dolphins and pilot whales, group size does not appear as a covariate, and the resulting estimates of ESW for false killer whales (2.0-2.3 km) is similar to that of other large delphinids. Because including other species increased the sample size for estimating the covariates in the line-transect model and because the ESW for false killer whales appears as an outlier in the previous analysis, we believe that our new estimates better characterize the abundance of false killer whales in the Hawaii EEZ study area. We cannot rule out the possibility that the visual detection of false killer whales is more related to group size than that for the other species. However, given the small sample size of false killer whale sightings, we believe that it is more likely that *TotGS* was selected in the best-fit-model of Barlow (2006) due to stochastic effects.

Although the acoustic methods used on this survey cannot yet be used to make an independent estimate of false killer whale abundance, the estimated fraction of total detections (visual plus acoustic) missed by the visual observers within the 4.5 km of the transect line (0.56) is entirely consistent with the expected fraction missed (0.58) based on the estimated line-transect parameters.

Passive acoustic monitoring added more to this survey than just showing that fraction of animals missed within the truncation distance is consistent with the estimated $f(0)$ and $g(0)$ parameters from the visual survey. Acoustic monitoring more than doubled the number of false killer whale groups that were detected and thereby increased the number of biopsy samples that were obtained for population genetic studies. Also, once a sighting was made, the acoustics team was able to guide the visual observers to the location of the animals for species identification and group size estimation. False killer whales often occur in very small subgroups and are extremely difficult to re-locate in rough weather. Certainly, some of the visually detected groups of false killer whales would not have been identified as such if acoustics had not been aiding in their re-location (unidentified false killer whales would most likely be recorded as "unidentified small whales" or "unidentified large delphinids"). Finally, the acoustic team was better able to determine when multiple subgroups existed, and this information prompted the visual observers to search for these subgroups and thereby improve their estimation of overall group size.

The coefficients of the line-transect covariates (Table 3) can be interpreted to indicate whether a specific covariate is positively or negatively related to detection distance and to indicate the approximate magnitude of the effect. Perpendicular sighting distances were greater for pilot whales than for false killer whales and were greater for false killer whales than for rough-toothed dolphins (*SppGrp*), were greater for the *McArthur* and *McArthur II* than for the *Jordan* (*Ship*), were greater for 25X binoculars than for naked eyes and 7X binoculars (*Bino*), were greater for mixed species groups than for single-species groups (*Mixed*), were greater when sea state was low (*Beauf*), were greater when the sighting cue was blows or "other" (splashes, birds, etc), and were greater when there was no sun glare on the trackline (*Glare*). Most of these effects make sense and could have been predicted *a priori*. The *McArthur II* has a highest sighting platform, which explains the greater sighting distances from this ship compared to the

Jordan. Animals are more conspicuous when they are producing visible blows, when they are splashing, or when they are associated with birds. Obviously calmer seas and higher power binoculars allow observers to see animals at a greater distance. The species that most frequently co-occurs with false killer whales, rough-toothed dolphins and pilot whales is the bottlenose dolphin (*Tursiops truncatus*). Bottlenose dolphins leap entirely out of the water more frequently than the other species considered here, which probably explains why mixed species groups are seen at greater distances. Rough-toothed dolphins are smaller and less conspicuous than false killer whales and they were seen on average at closer distances. Pilot whales are generally larger and more conspicuous than false killer whales and are seen at greater distances. The one counter-intuitive result is the greater sighting distances from the *McArthur* compared to the larger *McArthur II*.

The relative magnitude of the covariate coefficients (Table 3) indicates their relative contribution in explaining perpendicular sighting distances. The greatest effect is was due to the use of 25X binoculars compared to other sighting methods ($\Delta = 1.14$). The next largest effect is that of Beaufort sea state, with coefficients changing by 0.46 in going from Beaufort 1 to Beaufort 6 conditions. In interpreting these coefficients, however, it is important to remember that some of the factors are likely correlated (eg. animals may be more likely to be seen by naked eye when weather is rough and search distances are shorter).

Recommendations for Future Work

This paper demonstrates the value of passive acoustic monitoring to provide independent validation of the visual line-transect methods. However, there are additional steps that are needed to improve these methods and to ultimately develop independent line-transect estimates from the acoustic survey effort. There were numerous acoustic detections of “blackfish” (unidentified large delphinids) on the 2002 HICEAS cruise, but the ROCCA software was not available at that time to predict whether these were probable false killer whales. The approach used in this paper for PICEAS could be expanded to HICEAS by a post hoc analysis of all the recorded “blackfish” vocalizations to determine if they were likely to be false killer whales. The probabilities of a vocalization being a false killer whale can be quantified using ROCCA. This more quantitative re-analysis can also be done with the unidentified “blackfish” acoustic detections from PICEAS. As mentioned above, acoustic localization can aid in determining the number of subgroups present when a group is not all together. A more detailed acoustic analysis of the subgroups may help improve the estimation of overall group size and help us determine whether a group size correction factor that is specific to false killer whales might be required.

A full acoustic line-transect survey will require many more development. Species can usually not be determined with certainty from dolphin whistles, so a probabilistic method will need to be developed that explicitly allow for uncertainty in species determination. Group size cannot be determined with acoustics alone, so there will still be the need to close on groups and to visually estimate group size on acoustic line-transect surveys. However, smaller groups tend to vocalize less (Oswald 2006), so smaller groups will be more difficult to relocate (acoustically as well as visually), introducing a potential bias in estimates of group size for acoustic detections. Acoustic localizations are typically not made until the bearing angle to a group is between 45° to 90° from the bow. For species that react to the vessel (either attracted or repelled), this localization may occur after the group has already changed its location in response to the vessel. Methods are needed to better acoustically localize groups that are 3-4 miles ahead of the vessel.

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Table 1. Distribution of survey effort in the HICEAS and PICEAS study areas by geographic region and Beaufort sea state.

	Distance Surveyed (*L*)			
Geographic Region	**Calm Seas Beaufort 0-2 km**	**Moderate Seas Beaufort 3-4 km**	**Rough Seas Beaufort 5-6 km**	**Total Transect km**
Hawaii Main Islands	556	2,189	1,762	4,507
Hawaii Outer EEZ	918	8,470	5,762	15,150
HICEAS Total	**1,474**	**10,659**	**7,524**	**19,657**
Palmyra EEZ	136	1,560	517	2,213
Johnston EEZ	192	1,221	1,238	2,651
Other PICEAS	58	2,151	4,044	6,252
PICEAS Total	**386**	**4,932**	**5,799**	**11,116**

Table 2. Covariates selected for line-transect models that were within 2 AIC_c units ($\Delta AIC_c \leq 2$) of the best-fit model.

Line-transect model	**ΔAIC_c Value**
SpeciesGroup+Ship+Bino+Beauf+Mixed+Cue	0.15
SpeciesGroup+Ship+Bino+Beauf+Mixed+Cue+Rain/Fog	1.51
SpeciesGroup+Ship+Bino+Beauf+Mixed+Cue+Glare	0.00

Table 3. Coefficients associated with each factor level for those covariates that were selected in the best-fit model. Beaufort sea state was treated as a continuous variable.

Covariate Name	Factor Level	Coefficient
SpeciesGroup	False killer whales	0.000
	Pilot whales	0.052
	Rough-toothed dolphins	-0.294
Ship	David Starr Jordan	0.000
	McArthur	0.114
	McArthur II	0.047
Bino	25X binoculars	0.000
	eye & 7X binoculars	-1.145
Beauf	Beaufort sea state 1	-0.076
	Beaufort sea state 2	-0.153
	Beaufort sea state 3	-0.229
	Beaufort sea state 4	-0.305
	Beaufort sea state 5	-0.381
	Beaufort sea state 6	-0.458
Mixed	single-species group	0.000
	mixed-species group	0.134
Cue	cetacean (dorsal fin or body)	0.000
	blow	0.240
	other (splash, birds, etc.)	0.334
Glare	no glare on the trackline	0.000
	glare on the trackline	-0.148

Table 4. Size of geographic regions, number of sightings, mean group size, effective strip width (ESW), and estimated abundance and densities of false killer whales in the HICEAS and PICEAS study areas. Mean group sizes are corrected for a bias in estimating group size. Coefficients of variation (CV) are estimated by bootstrap and apply to both abundance and density estimates.

Region	Study Area km2 A	Number of Sightings n	Mean Group Size	Mean ESW	Abundance N	Density per 100 km2 D	CV Abundance and Density
Hawaii Main Island	212,900	0	na	na	0	0.000	na
Hawaii Outer EEZ	2,240,000	1	12.0	2.05	484	0.022	0.930
Hawaii Subtotal	2,452,900	1	12.0		484	0.020	0.930
Palmyra EEZ	349,500	4	7.0	2.18	1,329	0.380	0.646
Other PICEAS	1,842,500	3	4.9	2.32	906	0.049	0.680
PICEAS Subtotal	2,192,000	7	6.1	2.24	2,235	0.102	0.491

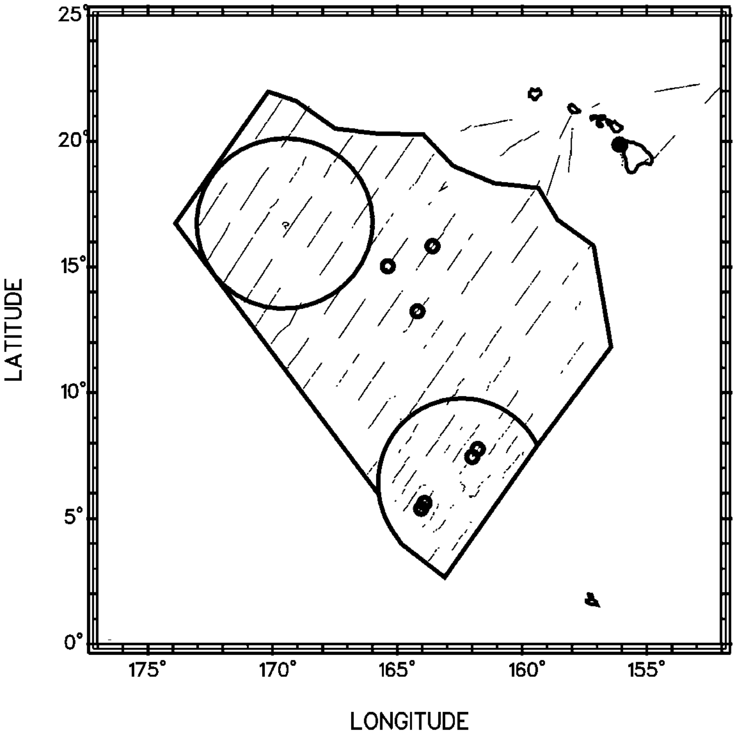

Figure 1. PICEAS study area showing the US EEZ of Palmyra Atoll and Kingman Reef (lower right) and Johnston Atoll (left). Fine lines show transects that were visually surveyed in Beaufort 0-6 conditions. Circles indicate on-effort sightings (n=8) of false killer whales (including one near Hawaii and outside the PICEAS study area).

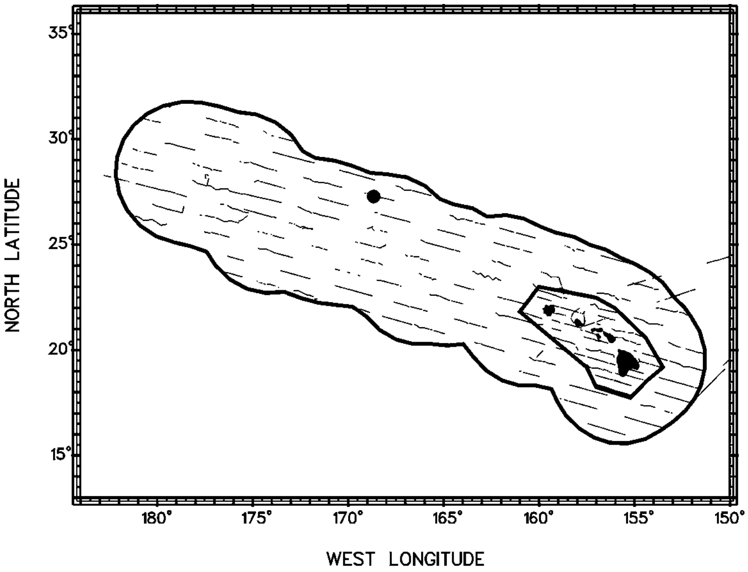

Figure 2. HICEAS study area showing the US EEZ of the Hawaiian Islands (outer bold line) and the Main Island stratum (inner bold line). Fine lines show transects that were visually surveyed in Beaufort 0-6 conditions. Circle indicates the one on-effort sighting of false killer whales.

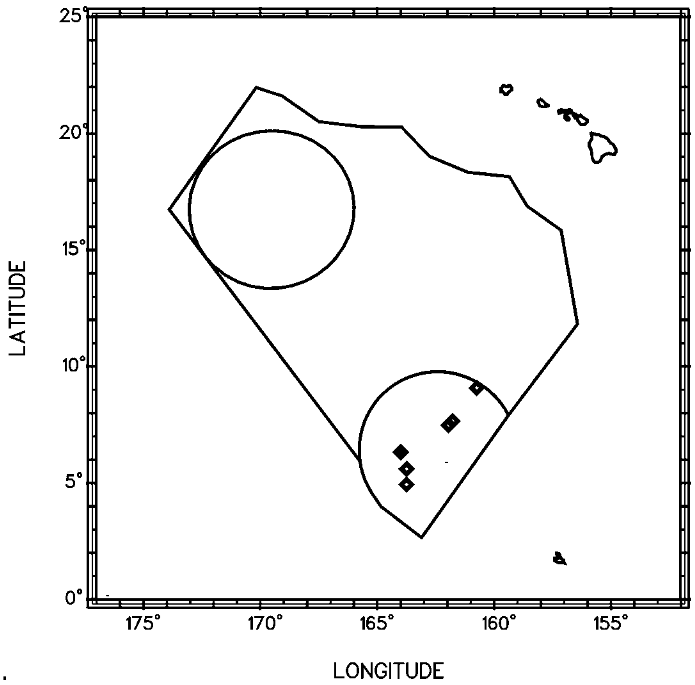

Figure 3. Location of acoustic detections of confirmed false killer whales (diamonds, n=6) that were missed by the visual line-transect survey. These confirmed detections were visually identified after they had passed abeam and had been obviously missed by the visual search team.

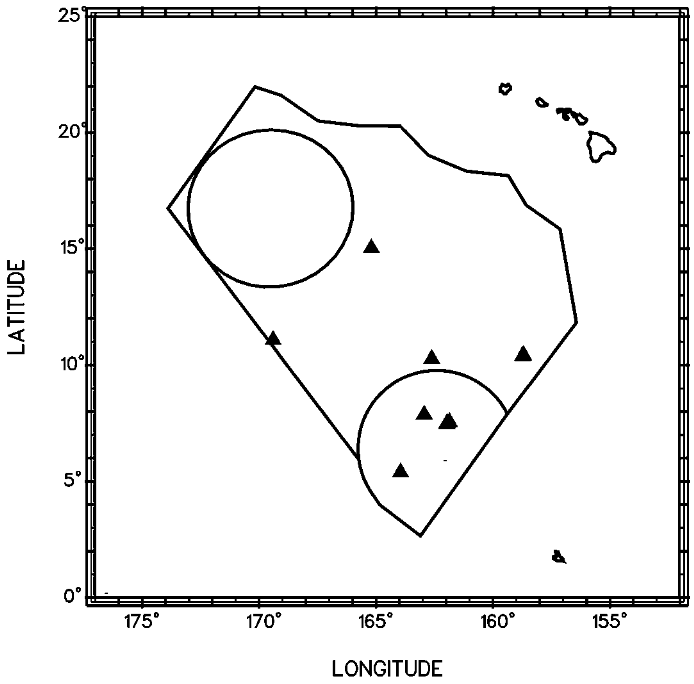

Figure 4. Location of acoustic detections of "possible" and "probable" false killer whales (triangles, n=11) that were missed by the visual line-transect survey (including one that was visually detected but classified as an unidentified small whale).