ABUNDANCE OF HUMPBACK WHALES IN HAWAIIAN WATERS: RESULTS OF 1993-2000 AERIAL SURVEYS

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Executive Summary

This report summarizes the results of aerial surveys of humpback whales conducted throughout the major Hawaiian Islands during the 1993, 1995, 1998 and 2000 winter seasons during their period of peak abundance (late Feb – early Apr). Identical methods were used throughout the series consistent with accepted distance sampling theory, thus permitting estimation of abundance and accurate assessment of trends across years.

Densities were calculated using DISTANCE (vers. 3.5) stratified by both depth category (0-99, 100-1000, >1000 fathoms) and year. Respiration data collected from earlier shorestation observations made across a six-year period were used to correct for the probability of detecting whales at the surface (g(0)). Corrected population estimates were as follows: **1993**: 2,754 (95% CI: 2,044-3,463); **1995**: 3,776 (95% CI: 2,925-4,627); **1998**: 4,358 (95% CI: 3,261-5,454); **2000**: 4,491 (95% CI: 3,146-5,836). Regression analysis revealed a significant linear trend of increasing densities across the seven-year intervening period [F(1,2) = 18.72, p < .05] with an average increase of 7% per year.

Comparisons with earlier estimates of abundance based on mark-recapture models applied to fluke identification photographs (e.g., Cerchio, 1998; Calambokidis et al. 1997) generally show the latter to be considerably higher than the survey-based estimates. The means of the estimates by Cerchio (1998) and Calambokidis et al. (1997) are 4,448 and 4,305 based on photographs from years 1989-93 and 1991-93, respectively. If the estimated rate of population increase of 7% per year is applied to these estimates, this suggests the current population to be approximately 6,800 whales. If the same rate of increase is applied to the survey-based estimate for 2000, there are currently about 4,800 whales. The discrepancy may represent over-estimates on the part of the mark-recapture estimates, perhaps deriving from violations of model assumptions (e.g., heterogeneity of sighting probabilities across regions) or from under-estimates on the part of the aerial survey estimates due to relatively short residency times on the part of individual whales. More data on average residency times of humpbacks in the Hawaiian Islands are needed to resolve this issue.

Introduction

Humpback whales (*Megaptera novaeangliae*) are a migratory species found in all of the world's oceans. They migrate to feeding grounds in the higher latitudes during the summer months, and to more tropical waters during the winter months to calf and breed. A prohibition on whaling of North Pacific humpbacks by member nations of the International Whaling Commission was instituted in 1966, after many years of intensive exploitation. Estimates of the size of the population at that time were approximately 1000 animals, compared with an estimated original abundance of at least 15,000 (Rice 1978; Johnson and Wolman 1984). The recovery of the North Pacific population of humpback whales from this endangered status is thus of continuing concern.

Baker et al. (1986) first proposed that the North Pacific population of humpback whales was comprised of several “structured stocks” consisting of relatively distinct breeding groups with only occasional interchange of individuals. Further analysis of photographic identification data (Calambokidis et al. 1997) and of mitochondrial and nuclear markers from biopsied specimens (Baker et al. 1998) supports the existence of three such stocks: An eastern stock that feeds in the waters off northern California and winters in island regions off the coast of the Mexican Baja Peninsula; a central stock that feeds in the waters off southeastern Alaska and winters in the main Hawaiian Islands; and a western stock that winters in the Ogasawara and Ryukyu Islands near Japan (feeding grounds unknown). Site fidelity tends to be strongest at the feeding areas with greater exchange among the three wintering areas (Calambokidis et al. 1997; Baker et al. 1998). Hawaii appears to be the most populous of the three wintering areas (Calambokidis et al. 1997).

Aerial surveys conducted in Hawaiian waters during the winter months (Jan-Apr) of 1976-80 showed humpbacks to be most prevalent in coastal regions and shallow banks where the expanse of water less than 100-fathoms (183 m) was more extensive (Herman and Antinoja, 1977; Herman et al., 1980; Baker & Herman, 1981). Greatest densities of adult humpbacks and calf pods were found in the "four island region" (FIR) consisting of Maui, Molokai, Kahoolawe and Lanai, as well as Penguin Bank. Replicating the methods of these earlier surveys during the 1990 winter season, Mobley, Bauer and Herman (1999) confirmed the earlier preference of both adult humpbacks and calf pods for the FIR and Penguin Bank regions, but also showed a substantial increase of adult humpbacks in the Kauai/Niihau region. They speculated that this increase represented a “spillover” of whales from formerly preferred habitat as a result of having reached a critical density threshold. Their results also showed a significant increase in encounter rates (whales/hr of survey) from the earlier (1977-80) to the later series (1990), particular for calf pods. This suggested that the wintering population had increased across the 10-13 yr intervening period. Analysis of the data from these earlier surveys was limited to comparisons of relative abundance since they did not use distance sampling methods. As a result, estimation of absolute abundance was not possible.

Prior to the 1993-2000 surveys reported here, abundance estimates were limited to mark and recapture methods applied to fluke identification photographs (see summary in Table 5). Mark and recapture approaches involve a choice among a wide range of possible models, including those assuming either closed populations (where members do not emigrate or immigrate) and those assuming open populations. Hammond (1986a) provides a thorough review of these models and potential sources of bias as applied to estimations of cetacean populations.

In their discussion of the structure and migration patterns of North Pacific humpback whales, Baker et al. (1986) used a mark and recapture approach to project abundance estimates for the Hawaiian wintering grounds and the southeastern Alaskan feeding grounds. They analyzed photographs taken during a six-year period from 1977-83. The weighted mean of the Petersen estimates suggested a population of 1,627 (95% CI: 1,320-1,924) for whales visiting Hawaii, vis-à-vis only 374 whales (95% CI: 327-421) for southeastern Alaska. The authors concluded that the Hawaii wintering population was four to six times larger than the summer feeding population in southeastern Alaska.

Using fluke photographs taken in the waters off W. Maui during the 1977-80 seasons, Darling and Morowitz (1986) estimated that approximately 1,000 whales visited Hawaii in one winter, and a total of 2,100 whales were in the wintering grounds across the five-years sampled. Baker and Herman (1987) criticized their estimates on the grounds that no confidence intervals were provided, and for the failure of the authors to consider a number of potential biases inherent in their approach. Baker and Herman applied several alternative models to their own photographic data, including Jolly-Seber and Peterson approaches, and concluded that the weighted Peterson model was likely more accurate. The latter produced an estimate of 1,407 whales (SE = 150) using photos from the 1980-83 seasons, also taken in the waters off W. Maui.

Calambokidis et al. (1997) analyzed fluke identification photographs gathered from investigators working throughout the North Pacific including all three known wintering grounds (Hawaii, Mexico and Japan) as well as feeding areas from California to the Aleutian Islands. Two models (Darroch and Hilborn) that incorporated migration rates among the three wintering areas, yielded estimates of approximately 6,000 humpbacks (4,000 for Hawaii, 1,600 for Mexico, and 400 for Japan). The authors concluded that the "best estimate" of the humpback whale population in the North Pacific was 6,010 (SE=474) based on the average of the estimates from the Darroch method. They suggested that, due to sources of bias such as a possible under-estimate for Mexico and the heavy favoring of males in the wintering grounds in general, the overall estimate may be as much as 2,000 whales more. Later analyses suggested a 6-8% annual increase for humpbacks in feeding grounds off the Washington, Oregon and California coasts (Calambokidis 1999).

Cerchio (1998) applied mark and recapture models to identification photographs of humpbacks taken off the island of Kauai during the years 1989 to 1993. He used six models that assumed closed populations (Chapman's modified Petersen, weighted mean of the Petersen, Darroch's maximum likelihood estimator, and Chao's M_t, M_h, and M_{th} estimators) and one open population model (Fisher-Ford estimator). Since the numbers of resights within each year were generally small, more precise estimates resulted when resights from all five years were included, with the majority of estimates ranging between 2,000 and 5,000 whales. Among the potential sources of bias, the problems of non-random mixing and resultant heterogeneity of individual sighting probabilities were cited as most problematic. He concluded that the abundance of whales in the

Hawaiian Islands was "likely close to 4000 individuals, and most probably between 3000 and 5000 animals" (p. 23).

During the years 1993, 1995, 1998 and 2000, marine mammal surveys were performed in waters adjoining all eight of the major Hawaiian Islands. These surveys used methods consistent with distance sampling theory (Buckland et al. 1993; Hammond 1986b) which permitted estimations of abundance. Further, since the same methods were used in all four years, trends in abundance across the seven-year intervening period could be determined. This report summarizes the results of the 1993-2000 surveys in detail, and compares these estimates with those obtained via photographic mark and recapture. A synopsis of the current status of the Hawaiian wintering population is provided at the end of the report.

Methods

Field Data Collection

Transect placement. The 1993-2000 surveys followed north-south systematic lines placed 14 nautical miles (nm) (26 km) apart with random legs connecting the endpoints (Figure 1). The north-south lines extended 7 (nm) (13 km) past the 1000 fathom limit which occurred at an average distance of approximately 25 nm (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 1. Summary of Flight Dates for 1993, 1995, 1998 and 2000 Surveys

Survey No.	1993 Dates	1995 Dates	1998 Dates	2000 Dates
1	Feb 21, 22, 23, 24, 26	Feb 28, Mar 1, 2, 3, 4	Feb 21, 24, 25, 27, Mar 1	Feb 21, 22, 24, 26
2	Mar 4, 5, 6, 8	Mar 8, 9, 10, 11	Mar 5, 6, 7, 8	Mar 4, 5, 6, 8
3	Mar 15, 16	Mar 18, 20, 23, 24, 25	Mar 13, 14, 15, 16	Mar 14, 15, 16, 20
4	Mar 24, 25, 26	Apr 1, 2, 3, 7	Apr 6, 7, 8, 17	Mar 29, 31, Apr 6, 7, 8

Data protocol. Location data from an onboard GPS receiver and altitude data from a radar altimeter were downloaded directly onto a laptop computer. Remaining data were manually recorded by the data recorder onto data sheets and later merged with the location and altitude data. Location and altitude data were automatically recorded at 30-sec intervals and manually recorded whenever a sighting occurred.

Personnel consisted of a data recorder and two observers, one on each side of the plane. When observers noted a sighting, they called out data to the data recorder regarding number of individuals, species, angle to the sighting (using a Suunto hand-held clinometer) and apparent reaction to the plane. The recorded sighting angle, in combination with the altitude data, allowed for estimation of perpendicular distance from the transect line to the sighting. Given the average recorded altitude of 238.5 m (sd = 52.7 m), errors of plus or minus one degree of angle yielded theoretical distance estimation errors of from ± 4.8 m at the maximum sighting angle of 70 degrees from horizontal (corresponding to the closest visible point), to ± 1,747 m at the maximum effective distance of approximately 5 km (sighting angle of 3 degrees ± one degree).

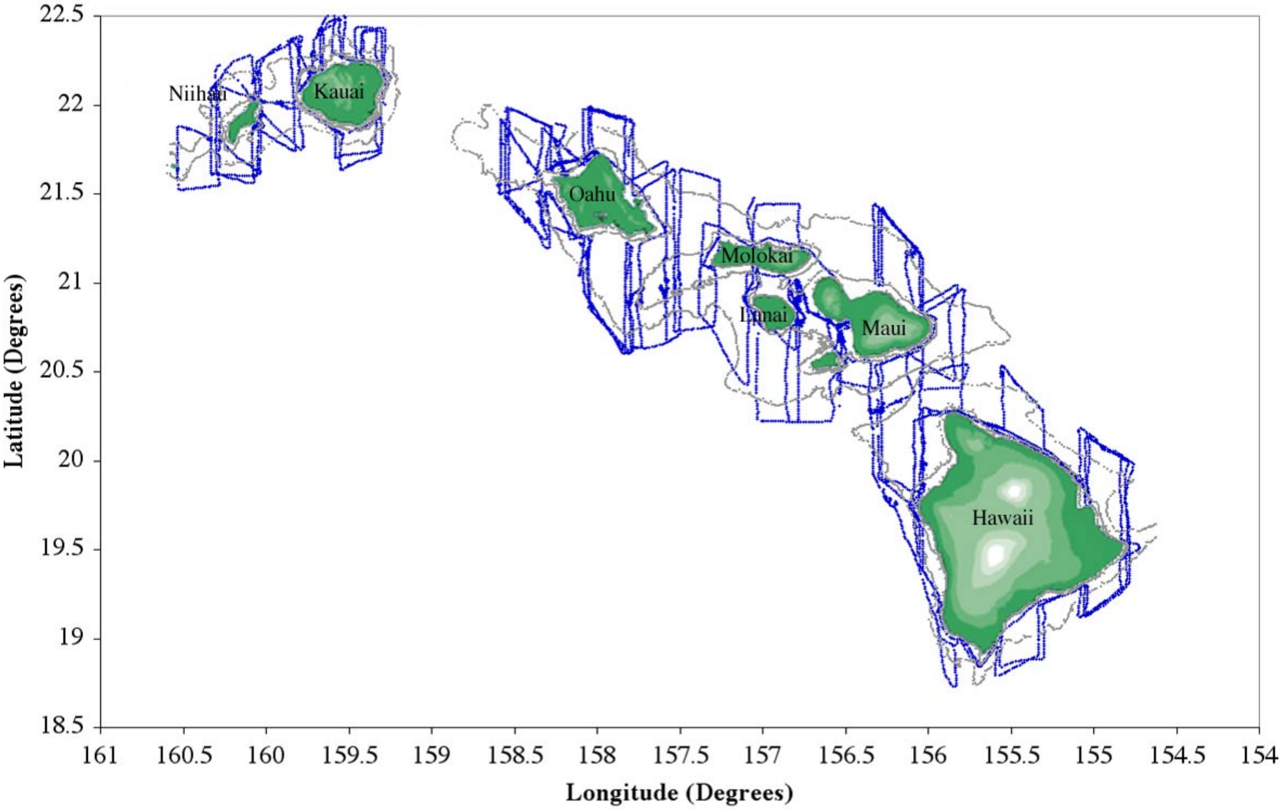

Figure 1. Sample tracklines used during 1993-2000 surveys. Consistent rules for generating tracklines were used across all four years surveyed (1993, 1995, 1998 and 2000) which resulted in nearly equivalent effort (tracklines for 2000 season shown).

<u>Abundance Estimation</u>

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 2). 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.

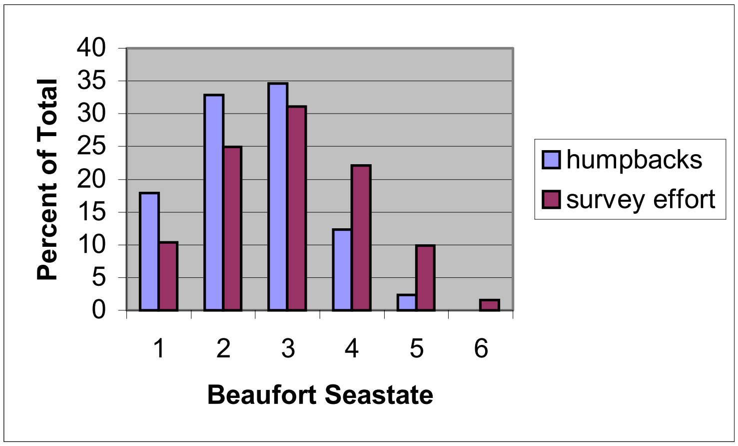

Figure 2. Effects of seastate on sighting probability (1993-2000). As shown, humpback sightings dropped sharply beyond a Beaufort seastate of 3.

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). Additionally, in order to reduce the influence of outlier estimates of perpendicular distance, the outer 5% of distance estimates were removed per the recommendations of Buckland et al. (1993). The resulting dataset was run through the DISTANCE program stratified by three depth strata (0-99, 100-1000 and >1000 fathoms) and four years (1993, 1995, 1998, 2000). This produced a total of 12 estimates of density (one for each of 12 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.

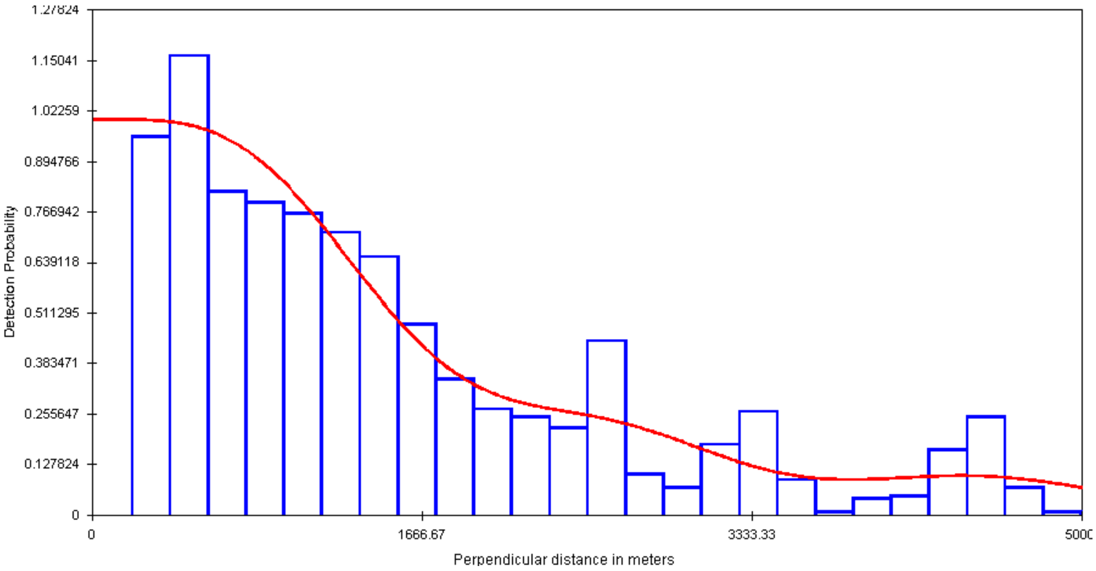

Figure 3. Perpendicular distance distribution and fitted probability density function of all humpback sightings within 5km distance of the trackline (with left truncation out to 200m).

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. 1993). 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, 1986b; Barlow, 1999). Here g(0) is calculated as the percent of time that a given species may be typically found at the surface.

Table 2 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 (Table 3) to produce corrected densities. These were in turn multiplied by the areas surveyed to produce corrected abundance estimates (Table 4).

Table 2. 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.

Results and Discussion

Abundance Estimates

Effort and Sightings. The surveys covered an area of 71,954 km^2, which included shallow near-shore waters and deep pelagic regions (Figure 1). Depth stratum 1 (<100 fathoms; < 183 m) included 7,561 km^2, depth stratum 2 (100-1,000 fathoms; 183-1830 m) included 30,266 km^2, and depth stratum 3 (>1,000 fathoms; >1830m) included 34,127 km^2. A total of 2,001 sightings of humpback whales were made during the four years surveyed (1993-2000) consisting of a total of 3,326 individual whales. Of these, only 1,330 sightings (66% of original) were used in the analysis. The remaining 34% 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 3.

Table 3. Summary of DISTANCE Results (Uncorrected)

Model Selected	Year	No. Groups in Analysis	Mean Group Size	Density (D)	CV (%)
Half Normal with	1993	253	1.67	.034	11.9%
Four Cosine	1995	563	1.64	.047	10.0%
Adjustments	1998	285	1.63	.054	11.5%
	2000	229	1.71	.057	14.2%

Density Trends (1993 to 2000). The half normal model, with four cosine adjustments, 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. The results of regression analysis revealed this trend to be significant [F(1,2) = 18.72, p<.05] with an average increase of 7% per year. If reliable, this suggests that the wintering humpback whale population will double in size approximately every 13 years. This estimated rate of increase is consistent with the earlier report of 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. When combined with the changes in relative abundance shown by the aerial survey results of Mobley, Bauer and Herman (1999, for years 1977-80 to 1990), these data suggest that the North Pacific population may be recovering.

Estimates of Abundance. In order to estimate abundance, the density values shown in Table 3 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 4 below summarizes these results and gives 95% confidence intervals of total abundance for each of the four years surveyed. These results are shown graphically in Figure 4. If the estimated rate of annual increase of 7% is applied to the estimated abundance for the year 2000, then the current estimated abundance (for year 2001) would be approximately 4,800 whales.

Table 4. Summary of Corrected Densities, Abundance Estimates and Confidence Intervals

Year	g(0)	CV g(0) (%)	Corrected Density (DC)	CV (DC) (%)	Corrected N	95% Confidence Interval: Min	Max
1993	0.2601	5.7%	0.1313	13.2%	**2754**	2044	3463
1995			0.1801	11.5%	**3776**	2925	4627
1998			0.2121	12.8%	**4358**	3261	5454
2000			0.2186	15.3%	**4491**	3146	5836

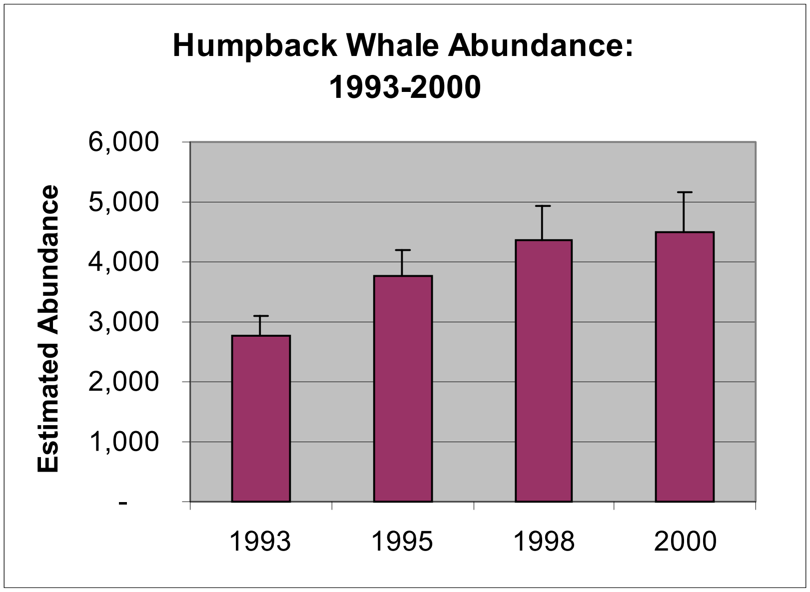

Figure 4. Corrected humpback whale abundance estimates based on 1993-2000 survey results.

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. 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.

Comparison with Previous Abundance Estimates

Table 5 below summarizes all previously published abundance estimates using accepted methods (i.e., either photographic mark-recapture models or distance sampling). The mark recapture estimates can be divided into an earlier (1977-83) and a later series (1989-93) based on when the photographs were taken. The estimates of the later series (i.e., Cerchio, 1998; Calambokidis et al. 1997) are consistently higher than those of the earlier ones (i.e., Baker et al. 1986; Darling & Morowitz, 1986; Baker and Herman, 1987). This increasing trend is consistent with the changes in abundance reported here for the 1993 to 2000 surveys, as well as the increase in relative abundance noted by Mobley, Bauer and Herman (1999).

One shortcoming of the mark and recapture estimates summarized here is that they have been generally limited to analyses of photographs taken from one or at most several island regions. This would not present a problem if the population of wintering humpbacks were randomly dispersed throughout all island regions. However, previous authors have noted the potential biasing effects of heterogeneous sighting probabilities across regions (e.g., Hammond, 1986a), i.e., when sampling is limited to just one region, certain types of whales may be under- or over-sampled. This possibility is suggested by the recent findings of Craig & Herman (2000) who showed that females seen in both the four island and Big Island regions were more likely to be accompanied by calves in the former case, among other regional differences. As Craig (2000) noted at the conclusion of her dissertation, “Overall, this study highlights the need for researchers working within a single area in the winter grounds to consider whether their findings should be generalized to the wintering population of humpbacks as a whole. The habitat preferences of different classes of whales may compromise the validity with which generalizations can be made” (p. 124).

Inspection of Table 5 reveals considerable variability among the mark-recapture estimates depending on what estimation model was used. For example, the estimates of Cerchio (1998) vary from a low estimate of 3,880 (Petersen) to 5,346 (Chao M_h) for the same data; a difference of 38%. However, the means of the five estimates by Cerchio (4,448) and the three estimates of Calambokidis et al. (4,305) are remarkably close, based on photographs of broadly overlapping periods (1989-93 and 1991-93, respectively). If we apply the estimated rate of population increase of 7% per year (from the survey results presented here) to the mean of these mark-recapture estimates, then the current Hawaiian wintering population would be approximately 6,800 whales. By comparison, applying the same rate of increase to the survey-based estimate for the year 2000 yields a current abundance estimate of approximately 4,800 whales using distance sampling. The discrepancy between the two approaches may represent an over-estimate on the part of the mark-recapture estimates; perhaps resulting from violations of the underlying assumptions of the models involved (e.g., heterogeneity of sighting probabilities across regions). Conversely, the discrepancy may result from under-estimates on the part of the aerial surveys, due to the fact that cohorts of whales are migrating to and from the islands at different times. If the latter is occurring, and the average residence times can be accurately determined, then this trend can be easily applied as a correction factor to survey-based estimates of abundance. More research on residency times, perhaps from satellite tagging studies (e.g, Mate, Gisiner and Mobley, 1997) will help to shed light on this issue.

In summary, the relative advantages of the aerial survey approach include: a) better resolution of abundance trends over relatively short periods of time; b) sensitivity to detecting changes in distribution across island regions (e.g., Mobley, Bauer and Herman, 1999); and c) standardized effort across all major island regions. Conversely, the relative advantages of the mark-recapture approaches include: a) their relative low cost, since they rely on analysis of existing archives of identification photographs; and b) their lower susceptibility to the influence of short residence times of individual whales.

Status of Hawaiian Wintering Population

The bulk of available evidence summarized here suggests that the Hawaiian wintering population, which represents the majority of the humpbacks in the North Pacific (Calambokidis, 1997; Baker et al. 1986), is increasing. If this increasing trend is stable, their continued status as endangered species will eventually require reassessment.

These increases are all the more impressive given the significant attention shown to the presence of humpbacks beginning in the 1970s. Whale-watching has become a significant tourist draw for Hawaii and is currently a major source of revenue. Whales are known to respond to the presence of vessels (Bauer, 1986). Yet the increased attention has not appeared to deter their population growth.

Many questions remain, however. For example, what factors define the carrying capacity of an environment where animals are not feeding? Humpbacks are not competing for any known resource other than reproductive ones. The fact that the distribution of whales around Kauai/Niihau had increased significantly across a 10-13 yr period (1977-80 to 1990) led Mobley, Bauer and Herman (1999) to speculate that animals were “spilling over” from previously preferred habitat (four island region) to new territory. If true, this suggests that spatial limitations exist, beyond which the whales are pressured to emigrate. Continued monitoring of their population and distribution trends is, therefore, recommended.

Table 5. Comparison of Abundance Estimates for Hawaiian Wintering Population of Humpback Whales (1986 - present) (in chronological order)

Source	Approach	Based on data from years (region):	Abundance estimate:
Baker et al. (1986)	Photo-identification mark and recapture	1977-83 (Maui only)	Petersen (weighted mean): **1,627** (SE = 157)
Darling & Morowitz (1986)	Photo-identification mark and recapture	1977-81 (Maui only)	Bernoulli: **1,000** (one season) **2,100** (all 5 yrs) (no SE provided)
Baker & Herman (1987)	Photo-identification mark and recapture	1980-83 (Maui only)	Petersen: **1,407** (SE = 150) (weighted w/ all years combined)
Cerchio (1998)	Photo-identification mark and recapture	1989-93 (Kauai only)	Model: Petersen: **3,880** (SE = 471)

Chao M_h: **5,346** (SE = 690)
Darroch M_t: **3,959** (SE = 439)
Chao M_t: **4,196** (SE = 514)
Chao M_{th}: **4,858** (SE = 685)

Table 5 (cont.)

Source	Approach	Based on data from years (region):	Abundance estimate:
Calambokidis et al. (1997)	Photo-identification mark and recapture	1991-93 (Maui, Kauai, Big Island)	Model: Darroch: **4,005** (SE = 381) Hilborn: **3,760** (SE = 439) Petersen: **5,151** (SE = 769)
Mobley, Spitz & Grotefendt (present report)	Aerial surveys using distance sampling	1993-2000 (All islands)	1993: **2,754** (SE = 362) 1995: **3,776** (SE = 434) 1998: **4,358** (SE = 559) 2000: **4,491** (SE = 686).

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