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U.S. DEPARTMENT OF COMMERCE
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Preliminary estimates of harbor porpoise abundance in Pacific Coast waters of California, Oregon and Washington, 2007-2012

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ABSTRACT

In this report, we present preliminary estimates of harbor porpoise abundance along the Pacific Coast of California, Oregon and Washington based on aerial line-transect surveys conducted between 2007 and 2012. Surveys were conducted in support of monitoring efforts for harbor porpoise (*Phocoena phocoena*) between central California and southern Oregon, and leatherback turtles (*Dermochelys coriacea*) in central California, northern Oregon, and Washington. Annual coverage and survey intensity varied by region, and two similar survey platforms were used (Partenavia and Twin Otter aircraft). For the Morro Bay and Monterey Bay harbor porpoise stocks, abundance was estimated based on previously established transects and based on alternate fine-scale transects. A geographically stratified line-transect analysis, with aircraft type as a covariate, was performed to estimate abundance (N) for the five harbor porpoise stocks found in this region: **Morro Bay**, N = 2,572 (coefficient of variation, CV = 0.44) for the traditional transects or N = 2,917 (CV = 0.41) for the fine-scale transects; **Monterey Bay**, N = 3,650 (CV = 0.46) and N = 3,715 (CV = 0.51) for traditional and fine-scale transects, respectively; **San Francisco-Russian River**, N = 9,886 (CV = 0.51); **Northern California-Southern Oregon**, N = 35,769 (CV = 0.52); and **Northern Oregon-Washington Coast**, N =

21,487 (CV = 0.44). Fine-scale survey estimates for Morro Bay and Monterey Bay stocks are similar to those using the previous transect design, but require less replication and may be a more cost-effective option for future surveys. Stock abundance estimates are similar to or greater than those reported from 2002-2007 survey data, but further analyses will be required to evaluate potential trends statistically.

INTRODUCTION

Five stocks of harbor porpoise are currently recognized along the outer Pacific coast of California, Oregon and Washington. The stocks (from south to north, Fig 1) are: (1) Morro Bay, from Point Conception to Point Sur; (2) Monterey Bay, from Point Sur to near Pigeon Point (N37º11.7’); (3) San Francisco – Russian River, from near Pigeon Point to just north of Point Arena (N39º12.7’); (4) Northern California – Southern Oregon, from just north of Point Arena to Lincoln City, OR (N45º). Stock boundaries are based on molecular genetic differences, pollutant concentration differences, density minima observed from aerial surveys, and known habitat discontinuities (Chivers et al. 2002). This document presents updated estimates of abundance for all five stocks based on a variety of aerial line-transect surveys conducted between 2007 and 2012.

METHODS

Study areas and transect design

A variety of aerial surveys that used identical data collection protocols were conducted between 2007 and 2012. The primary set of harbor porpoise aerial surveys (HPAS) was conducted in 2007 and 2011 along inshore and offshore zigzag transects between Pt. Conception, California and the California/Oregon border. These HPAS transects have been repeated at 2-5 year intervals since 1991 (Carretta et al. 2009). The inshore stratum extends from the coast out to the 92-m (50-fathom) isobath, and inshore transects were replicated multiple times, as weather permitted. Offshore transects extend out to the 200-m isobath or a minimum distance from shore (18.5 km south of 37 º N, 27.8 km north of this latitude; Carretta et al. 2009) and were flown once, weather permitting. During 2011, the inshore and offshore HPAS transect lines were extended northward to about Cape Blanco, OR (42º 49.6’ N) using a similar zigzag (Figure 1). Additional surveys along the central California portion of these transects were conducted as part of leatherback turtle (*Dermochelys coriacea*) studies during 2007-2011.

Two separate aerial surveys for leatherback turtles were conducted during 2010 and 2011 from the coast approximately to the 2000-m isobath between Cape Blanco, OR and Cape Flattery, WA (Figure 2). Combined with the extended HPAS surveys, this provided complete coverage of California, Oregon and Washington outer coastal waters for harbor porpoise abundance estimation. Some additional adaptive surveys were conducted in areas of special interest for leatherback turtles; although these transects were not included in the analysis, the corresponding harbor porpoise sightings were included for estimation of the detection function in this study

Additional fine-scale surveys were conducted within the ranges of the Monterey Bay and Morro Bay harbor porpoise stocks (Figure 3). The Monterey Bay survey was conducted during 2011 to evaluate an alternate survey design for harbor porpoise abundance estimation in this area. The Morro Bay fine-scale surveys were conducted as part of a monitoring study for high-energy seismic surveys planned for the fall of 2012 (but subsequently canceled), and were designed in a stratified manner (three strata) to increase coverage in the nearshore porpoise habitat where seismic surveys were planned, while also providing complete coverage of the entire Morro Bay stock range to detect potential stock-wide movement patterns.

Field methods

Field methods were identical during all harbor porpoise and leatherback surveys, and many of the same observers participated in both projects. Surveys were flown at an altitude of about 198 m (650 ft) and airspeeds of 165-175 km/hr (90-95 kts). Most (16 out of 25) of the HPAS surveys and all of the fine-scale surveys were conducted in Partenavia P-68 (standard or observer models). The Oregon/Washington leatherback surveys and nine HPAS surveys flown in central California in support of leatherback studies were conducted in a DeHavilland Twin Otter (Table 1). In both aircraft types, two observers searched from bubble windows on either side of a twin-engine, high-wing aircraft, while a third observer searched from a belly port in the rear of the aircraft. Sighting information, including species, number of animals, and declination angle (measured with a Suunto™ hand-held clinometer), was verbally reported to a data recorder who entered sighting and environmental data into a laptop computer with real-time GPS input using a customized program. All marine mammals (except California sea lions, *Zalophus californianus* [1]) and sea turtles were recorded systematically. Further details on the survey methodology and aircraft are found in Forney (1995, 1999) and Benson et al. (2007).

Analytical methods

Raw data were error-checked and edited at the end of each survey day, and subsequently processed for import into the line-transect analysis software *Distance 6.0* (Thomas *et al.* 2009) for abundance estimation. Only transect data collected under excellent survey conditions (Beaufort sea state ≤ 2 and cloud cover ≤ 25%) were used in the present analysis to estimate porpoise abundance. The detection function, *f(0)* was modeled based on pooled sightings for all survey types combined. Based on past analyses of harbor porpoise survey data (Carretta et al. 2009), a half-normal model with cosine adjustments was fit to the perpendicular sighting data. Analyses were conducted using conventional distance sampling (CDS) and multiple covariate distance sampling (MCDS) to allow for potential effects of aircraft type (Partenavia vs. Twin Otter), sea state (Beaufort 0-2), and glare direction (left, right, front, or rear of viewing area). Target species (harbor porpoise vs. leatherback turtle) was not included as a potential covariate because survey protocols were identical on all flights. The model with the lowest Akaike's Information Criterion (AIC) and best goodness of fit results was selected to estimate density and abundance. Several combinations of truncation distances ranging from 200-400 m were explored during model fitting and a 300 m truncation distance (*w*) was selected (resulting in elimination of the most distant 2.3% of sightings). Potential differences in mean group size among stocks were evaluated using analysis of variance. A cluster size-bias regression method that regresses the natural logarithm of observed group size against *g(x)*, the estimated detection probability at distance *x*, was used to correct for potential bias caused by missing small porpoise groups at greater distances.

Eight geographic strata were defined for analysis of the HPAS surveys, dividing the transects

[1] This species was not recorded during most flights because its great abundance would interfere with the detection and recording of the target species, harbor porpoise and leatherback turtles.

inshore/offshore and at the harbor porpoise stock boundaries (Fig. 1). The Oregon/Washington leatherback surveys were divided into two strata at 45º N to separate the Northern California - Southern Oregon stock and the Northern Oregon - Washington Coast stock (Fig. 2). The Monterey Bay fine-scale survey included only a single stratum, while the Morro Bay fine-scale survey was divided into three strata to reflect the different intensity of survey lines inshore/offshore and along the narrow shelf of the Big Sur coastline north of about 36º 10' N (Fig. 3). Harbor porpoise density, D_i, and abundance N_i, were estimated separately for each geographic stratum using the following equations (Buckland et al. 2001):

$$D_i = \frac{n_i \cdot E(s_i)}{2 \cdot L_i \cdot g(0) \cdot ESW_i} \tag{1}$$

and

$$N_i = A_i \cdot D_i \tag{2}$$

where

n_i	=	number of porpoise groups detected in stratum *i*,
L_i	=	length of transect line (in km) surveyed in stratum *i*,
$E(s_i)$	=	expected group size in stratum *i* at zero perpendicular distance,
$g(0)$	=	probability of detecting a porpoise group on the transect line,
A_i	=	size of the study area in stratum *i* (in km^2), and
ESW_i	=	effective strip half-width (in km) in stratum *i*.

For CDS, ESW_i is calculated as the inverse of $f(0)$, the probability density function (km^{-1}) evaluated at zero perpendicular distance. For MCDS analyses, ESW_i is calculated as the product of the truncation distance *w* and the average probability of detection, $\bar{p}_i$, for the n_i porpoise groups encountered in stratum *i* (Buckland et al. 2004).

The probability of detecting a group of porpoises on the transect line, $g(0)$ = 0.292, CV = 0.366, is taken from the study of Laake et al. (1997), which also took place under excellent survey conditions, using a Partenavia aircraft and the same survey methods as in this study.

Although we attempted to complete each transect the same number of times, weather conditions and varying survey objectives for leatherback vs. harbor porpoise flights resulted in uneven within-stratum coverage in some cases. To avoid potential within-stratum bias caused by uneven coverage, transect-specific encounter rates were weighted according to the proportional contribution of that transect within the stratum, yielding a weighted encounter rate (n_i/L_i) for each geographic stratum. This was done for inshore strata only, as sparse offshore effort resulted in most offshore transects being surveyed no more than once in a given year. For weighted estimates, the encounter rates were calculated following the methods described in Benson et al. (2007):

$$\frac{n_i}{L_i} = \sum_{j=1}^{k} \frac{t_{ij}}{T_i} \frac{n_{ij}}{L_{ij}} \qquad (3)$$

where

k = the total number of transects within stratum i;

t_{ij} = the length (in km) of the j_{th} transect in stratum i;

T_i = the total length of all transects in stratum i;

n_{ij} = the number of porpoise sightings seen on transect j in stratum i; and

L_{ij} = the actual distance flown on transect j within stratum i.

Variances and coefficients of variation (CV) for the encounter rate (n_{ij}/L_{ij}), ESW_i, and $E(s_i)$ were estimated empirically within *DISTANCE*. Stratum-specific variance in harbor porpoise abundance was estimated from these individual variances components using the following formula:

$$CV(N_i) = \sqrt{CV^2(E(S_i)) + CV^2(\frac{n_i}{L_i}) + CV^2(ESW_i) + CV^2(g(0))} \qquad (4)$$

Combined estimates of porpoise abundance (N) were estimated for each of the five harbor porpoise stocks by adding the stratified abundance estimates within each stock's range. Variances were combined using standard formula to calculate stock-wide CVs and log-normal 95% confidence intervals (Buckland et al. 2001).

RESULTS

Survey effort varied considerably by year, with approximately 38% of all effort occurring in 2011 and 5-16% in each of the other four years (Table 1). A combined total of 1,006 harbor porpoise groups were sighted within the 300-m truncation distance during 12,900 km surveyed in good conditions (Beaufort sea states 0-2 and cloud cover ≤ 25%; Table 1), and an additional 56 porpoise sightings were made during adaptive leatherback surveys. These additional sightings contributed to the detection function and mean group size estimation, but the adaptive surveys were otherwise not included in the analysis. The transects completed in excellent conditions broadly covered most of the California/Oregon inshore harbor porpoise strata and the entire Oregon/Washington study area (Fig. 4). In contrast, weather limitations caused gaps in coverage for some of the offshore strata, most notably off northern California and Oregon (Fig. 5) Differences between abundance estimates obtained with and without group size bias corrections were small (<3%) and size-bias corrected estimates are presented here. There were no significant differences in mean group size among stocks (P = 0.10), so the average $E(s)$ = 1.74 value was used for all stocks. The MCDS model fit that included aircraft type as a covariate had the lowest AIC value (Table 2) and was selected for abundance estimation, resulting in stratum-specific detection probabilities (and resulting average *ESW* values) that reflected the use of each aircraft type within that stratum. The distributions of perpendicular sighting distances differed slightly (Fig 6), and effective strip width was narrower for the Twin Otter (150 m, standard error SE = 6.4) than for the Partenavia (165 m, SE = 5.1).

Total estimated abundances for the five harbor porpoise stocks (Table 3) are generally similar to past estimates reported by Carretta et al. (2009) for surveys from 2002-2007, although the point estimates for the Morro Bay, Monterey Bay, and Northern Oregon - Washington Coast stocks are greater than previous estimates. We did not test for statistical differences between these two sets of estimates because the two datasets share common parameters of $g(0)$ and data for 2007, but the confidence intervals overlap so these difference may reflect sampling variation rather than an increase in abundance. The traditional HPAS surveys and the new fine-scale surveys for Morro Bay and Monterey Bay yielded similar estimates of abundance (Table 3).

DISCUSSION

Although this study draws on a variety of surveys for harbor porpoise and leatherback turtles, the combined survey effort was sufficient to estimate abundance throughout the Pacific coast range of this species and for five separate harbor porpoise stocks. The estimates presented in this study are similar to those reported previously (Carretta et al. 2009, based on overlapping 2002-2007 data) for the three northern stocks, from just south of San Francisco northward. Carretta et al. (2009) estimated 9,189 (CV = 0.38) porpoises for the San Francisco Russian River stock, compared to 9,886 (CV = 0.51) in this study. The previous estimate of 39,581 (CV = 0.39) for the Northern California – Southern Oregon stock (Carretta et al. 2010) is also similar to the estimate of 35,769 (CV = 0.52) in this study. The Northern Oregon and Washington Coast stock estimates presented here (21,487, CV = 0.44) are greater than the previous 2002 estimate of 15,674 (CV = 0.39), but the previous estimate is within the confidence limit of the current abundance.

Abundance estimates of about 2,600-3,700 for the two southernmost stocks (Table 3), are greater than the previous 2002-2007 estimates of 2,044 (CV = 0.40) for Morro Bay and 1,492 (CV = 0.40) for Monterey Bay (Carretta et al. 2009), but additional analyses will be required to determine whether the estimates differ statistically [the two estimates cannot be directly compared without additional analyses, because they rely on some of the same data and estimate of the parameter g(0)]. Bayesian methods that take such a lack of independence into account (Moore and Barlow 2011) may be useful to evaluate potential trends for these two stocks. A confirmed increase could suggest continued recovery of these two stocks from impacts of gillnet bycatch during the 1980s and 1990s. Most gillnets were banned within the central California range of harbor porpoise in 2002 (Barlow and Forney 1994, Forney 1999; Forney et al. 2001; Carretta et al. 2010).

The platform differences between the Partenavia and the Twin Otter were somewhat surprising, because these aircraft are configured very similarly, with lateral bubble windows and a belly viewing port, and we employed identical data collection methods and many of the same observers in each aircraft. The histograms of perpendicular sighting distances (Fig. 6) suggest that the Twin Otter's narrower ESW is caused by a greater proportion of sightings closer to the transect line, while the Partenavia appears to have a greater proportion of sightings between 70 m and 120 m and an apparent deficit of sightings within 60 m of the transect line. Potential factors in causing these pattern could include 1) rounding error for the reported angles (especially in the belly, where angles are estimated from tick marks because there is insufficient space to use a clinometer), 2) the smaller belly window in the Partenavia compared to the Twin Otter, and/or 3) the larger and deeper bubble windows in the Twin Otter, which allow better downward (trackline) viewing and could reduce the number of detections farther from the transect line. The multiple covariate distance sampling analysis applied in this study, combined with the large numbers of sightings on both aircraft, allowed the estimation of stratum-specific detection probabilities based on the proportion of effort conducted on each platform. Further investigations into the sources of these differences and any potential biases are warranted.

The comparison of traditional HPAS surveys and fine-scale surveys yielded estimates that were remarkably similar within the two southern strata where both survey types were conducted (Table 3), although the CV was slightly greater for the fine-scale survey, likely because of the smaller number of sightings. In the case of Monterey Bay, the fine-scale estimate was obtained with about 1/3 of the replicated survey effort along the HPAS zigzag transects. The Monterey Bay fine-scale survey can be completed in a single 4-5 hr flight, compared to multiple survey bouts (during limited good-weather opportunities) over the course of the fall/summer period for the replicated zigzag; thus the fine-scale design may offer a cost- and time-effective alternative for future surveys. The fine-scale Morro Bay surveys, which were designed to monitor harbor porpoise distribution and density before, during, and after planned 2012 seismic surveys, were replicated 3x inshore and 2x offshore, and thus included a similar amount of effort as the HPAS surveys. The difference of about 350 porpoises between these two estimates (Table 3) is in part attributable to the zero estimate in the HPAS offshore stratum, which had a low level of coverage and did not yield any harbor porpoise sightings. In contrast, the greater survey effort in offshore waters during the fine-scale surveys resulted in the detection of a few porpoises, yielding an estimate of 309 animals in the offshore stratum. A single replicate of the fine-scale inshore and offshore Morro Bay surveys can be completed in a single day (two 4-hr flights), and appears to be a cost-effective method of assessing this stock.

The revised abundance estimates presented in this report are preliminary and intended to allow updated stock assessment reports for harbor porpoise along the Pacific coasts of California, Oregon and Washington. Minimum abundance estimates, defined as the lower 20th percentile of the estimated abundance, are provided in Table 7 for each survey design.

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Table 1. Summary of survey dates, types, aircraft used, total search effort (km), and sightings (# Si) by viewing conditions. HPAS = Harbor porpoise aerial surveys; OR/WA = Oregon / Washington leatherback surveys. See Figs 1-3 for transect design by survey type.

	Survey	Aircraft	All Conditions		Excellent Conditions		% Excellent Conditions	
Survey Type	**Date**	**Type**	**# Si**	**km**	**# Si**	**km**	**Sightings**	**km**
HPAS	05/23/2007	Partenavia	16	336.8	14	61.6	88%	18%
HPAS	08/07/2007	Partenavia	8	329	3	27.3	38%	8%
HPAS	08/28/2007	Twin Otter	3	87.3	3	87.3	100%	100%
HPAS	08/30/2007	Twin Otter	14	507.1	9	294.9	64%	58%
HPAS	09/24/2007	Partenavia	31	515.6	28	373.9	90%	73%
HPAS	09/25/2007	Partenavia	43	680.4	41	578.3	95%	85%
HPAS	09/26/2007	Partenavia	118	687.6	115	631.8	97%	92%
HPAS	08/28/2008	Twin Otter	45	420.5	44	406.5	98%	97%
HPAS	09/26/2008	Twin Otter	14	695.3	11	232.6	79%	33%
HPAS	09/30/2008	Twin Otter	23	770.8	23	665.9	100%	86%
HPAS	11/06/2008	Partenavia	50	563.7	49	364.8	98%	65%
HPAS	05/17/2009	Twin Otter	97	719.2	96	497.2	99%	69%
HPAS	06/03/2009	Twin Otter	17	608.5	0	50.9	0%	8%
HPAS	06/04/2009	Twin Otter	4	98.9	4	44.4	100%	45%
HPAS	04/13/2010	Twin Otter	13	449.1	3	59.8	23%	13%
OR/WA	09/10/2010	Twin Otter	9	845	6	277.2	67%	33%
OR/WA	09/11/2010	Twin Otter	8	778.2	5	456.9	63%	59%
OR/WA	09/13/2010	Twin Otter	2	402.6	0	54.6	0%	14%
OR/WA	09/21/2010	Twin Otter	12	728.7	8	424.1	67%	58%
OR/WA	09/22/2010	Twin Otter	20	819.8	6	418	30%	51%
HPAS	10/06/2010	Partenavia	30	303.2	21	87.6	70%	29%
OR/WA	09/11/2011	Twin Otter	15	812.5	10	423.2	67%	52%
OR/WA	09/16/2011	Twin Otter	16	690.1	16	368.8	100%	53%
OR/WA	09/19/2011	Twin Otter	13	734.8	12	537	92%	73%
HPAS	09/20/2011	Partenavia	58	508.2	57	466.3	98%	92%
OR/WA	09/20/2011	Twin Otter	25	758.8	16	354.1	64%	47%
HPAS	09/21/2011	Partenavia	23	196.9	20	126.4	87%	64%
OR/WA	09/21/2011	Twin Otter	21	251.5	8	81.4	38%	32%
OR/WA	09/29/2011	Twin Otter	18	488.9	6	291.3	33%	60%
HPAS	10/08/2011	Partenavia	47	320.5	46	246.8	98%	77%
HPAS	10/11/2011	Partenavia	12	162.1	12	108.8	100%	67%
HPAS	10/12/2011	Partenavia	9	36.4	6	8.1	67%	22%
HPAS	10/13/2011	Partenavia	91	497.5	75	316.9	82%	64%
HPAS	10/26/2011	Partenavia	3	246	1	80.1	33%	33%
HPAS	10/27/2011	Partenavia	76	806.1	66	679.2	87%	84%
HPAS	12/10/2011	Partenavia	24	618.6	16	312.7	67%	51%
Fine-scale (Monterey Bay)	12/17/2011	Partenavia	44	635.3	44	554.5	100%	87%
Fine-scale (Morro Bay)	10/02/2012	Partenavia	31	504.5	31	462	100%	92%
Fine-scale (Morro Bay)	10/18/2012	Partenavia	22	307	20	233	91%	76%
Fine-scale (Morro Bay)	10/28/2012	Partenavia	21	369.4	12	175.6	57%	48%
Fine-scale (Morro Bay)	11/05/2012	Partenavia	41	776.1	41	702.8	100%	91%
Fine-scale (Morro Bay)	11/06/2012	Partenavia	2	282.2	2	275	100%	97%
Total			**1189**	**21351**	**1006**	**12900**	**85%**	**60%**

Table 2. Model fitting results for the detection function models evaluated, including covariates for aircraft type, glare direction, and Beaufort sea state. MCDS = multiple covariate distance sampling, CDS = conventional distance sampling, AIC = Akaike's Information Criterion, Δ AIC = difference in AIC from vs. the model, Mean ESW = average effective strip half-width for entire data set (in km), CV(ESW) = coefficient of variation of ESW.

Model Type	Covariate(s)	No. of parameters	AIC	Δ AIC	Mean ESW	CV(ESW)
MCDS	Aircraft type (Partenavia or Twin Otter)	2	11691.86	0.00	0.1600	0.02
CDS	-	1	11693.49	1.63	0.1603	0.03
MCDS	Glare direction (left, right, front, rear)	3	11695.20	3.34	0.1601	0.02
MCDS	Beaufort sea state (0-2)	3	11695.34	3.48	0.1603	0.02

Table 3. Line-transect parameter estimates and estimates of harbor porpoise density and abundance by stratum and stock area. Key: n= number of groups seen, L = survey effort, A = stratum area, wt n/L = weighted group encounter rate, CV= coefficient of variation, ESW = effective strip width, D_u and N_u = uncorrected density and abundance (assuming *g(0)*=1), g0 = probability of detecting a group on the transect line, D and N = corrected density and abundance, and N_{min} = lower 20th percentile of the abundance estimate.

Harbor Porpoise Stock:	**Morro Bay**					**Monterey Bay**			**San Fran - Russ. River**		**N California - S Oregon**			**N OR - WA**
Survey type:	**HPAS**		**Fine-scale**			**HPAS**		**Fine-scale**	**HPAS**		**HPAS**		**OR/WA**	**OR/WA**
Stratum:	**Inshore**	**Offshore**	**Inshore E-W**	**Inshore HPAS**	**Offshore Zig-zag**	**Inshore**	**Offshore**	**Monterey Bay**	**Inshore**	**Offshore**	**Inshore**	**Offshore**	**Oregon S of 45° N**	**OR/WA N of 45° N**
n	100	0	100	4	2	155	6	44	243	38	220	1	28	65
L (km)	1184	93	1138	203	508	1122	286	555	2399	735	887	105	898	2789
A (km^2)	1851	4335	1577	273	4335	1193	1997	2585	3635	5582	4541	8240	20070	46016
wt n/L	0.076	0.000	0.088	0.020	0.004	0.124	0.022	0.079	0.095	0.030	0.268	0.008	0.031	0.023
CV (n/L)	0.23	-	0.14	0.76	0.71	0.17	0.53	0.34	0.10	0.27	0.16	1.00	0.28	0.22
E(s)	1.75	1.75	1.75	1.75	1.75	1.75	1.75	1.75	1.75	1.75	1.75	1.75	1.7489	1.7489
CV (E(s))	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
ESW (km)	0.163	0.163	0.165	0.165	0.165	0.160	0.152	0.165	0.159	0.151	0.165	0.165	0.150	0.150
CV (ESW)	0.07	0.07	0.07	0.34	0.47	0.06	0.29	0.10	0.04	0.11	0.05	0.05	0.13	0.09
D_u	0.406	0.000	0.465	0.104	0.021	0.678	0.129	0.420	0.524	0.176	1.416	0.044	0.182	0.136
CV D_u	0.24	0.00	0.16	0.83	0.85	0.18	0.60	0.36	0.11	0.29	0.16	1.00	0.31	0.24
N_u	751	0	733	28	90	809	257	1,085	1,906	981	6,428	359	3657	6274
g0	0.292	0.292	0.292	0.292	0.292	0.292	0.292	0.292	0.292	0.292	0.292	0.292	0.292	0.292
CV(g0)	0.37	0.37	0.37	0.37	0.37	0.37	0.37	0.37	0.37	0.37	0.37	0.37	0.37	0.37
D	1.390	0.000	1.592	0.357	0.071	2.321	0.441	1.437	1.796	0.602	4.848	0.149	0.624	0.467
N	2,572	0	2,511	97	309	2,769	881	3,715	6,528	3,358	22,014	1,229	12,525	21,487
CV(N)	0.44	0.00	0.40	0.91	0.93	0.41	0.71	0.51	0.38	0.47	0.40	1.07	0.48	0.44
Stock-specific	**Morro Bay**					**Monterey Bay**			**San Fran - Russ. River**		**N California - S Oregon**			**N OR - WA**
Estimates	**HPAS 2007-2011**		**Fine 2012**			**HPAS 2007-2011**		**Fine 2011**	**HPAS 2007-2011**		**HPAS 2007-2011 and OR 2010-2011**			**2010-2011**
N	**2,572**		**2,917**			**3,650**		**3,715**	**9,886**		**35,769**			**21,487**
CV (N)	**0.44**		**0.41**			**0.46**		**0.51**	**0.51**		**0.52**			**0.44**
L95%(N)	1136		1357			1548		1447	3884		13756			9468
U95%(N)	5828		6271			8604		9537	25163		93004			48762
N_{min}	**1812**		**2102**			**2528**		**2480**	**6625**		**23749**			**15123**

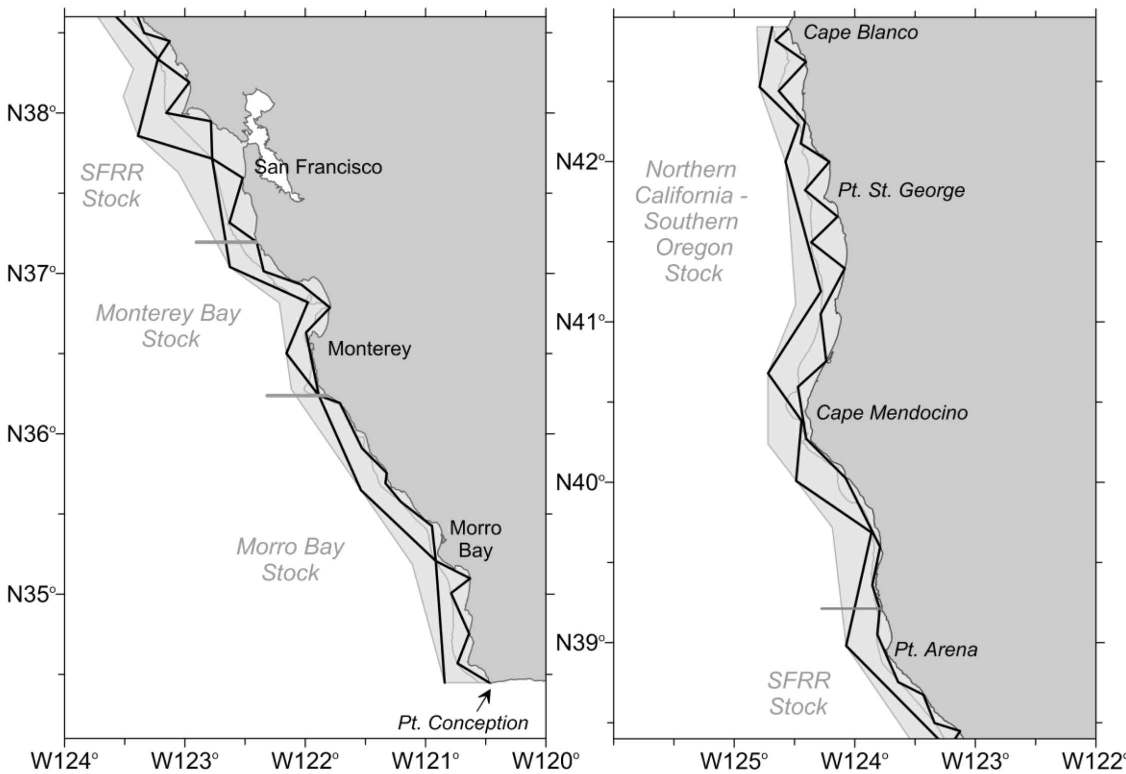

Figure 1. Inshore and offshore harbor porpoise aerial survey (HPAS) transects (black lines) along the California and southern Oregon coast. Light gray shading is the study area boundary. Stock boundaries and names are indicated with gray lines and gray font (SFRR = San Francisco-Russian River Stock).

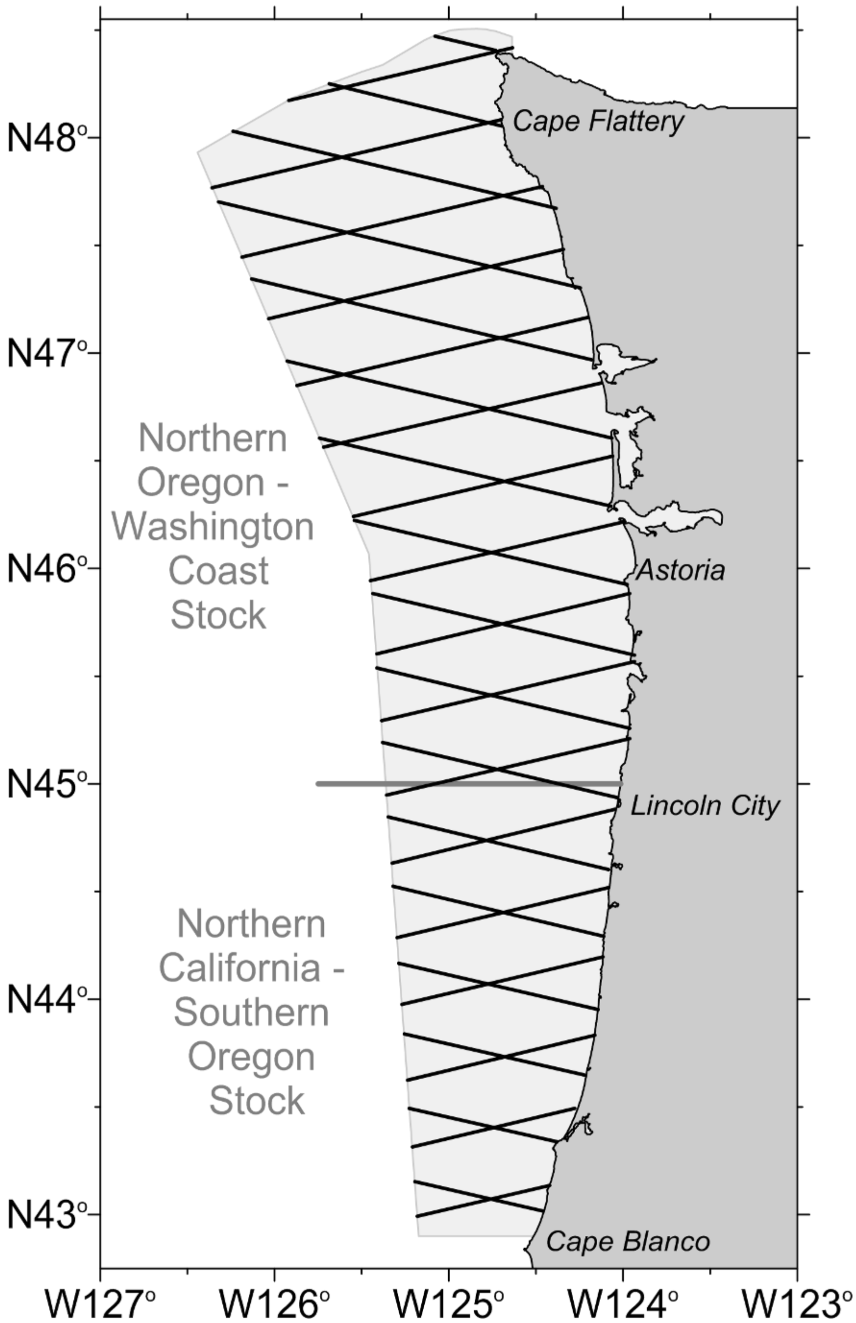

Figure 2. Oregon and Washington (OR/WA) leatherback turtle aerial survey transects (black lines), extending offshore to about the 2000-m isobath. Light gray shading is the study area boundary. Stock boundaries and names are indicated with gray lines and gray font.

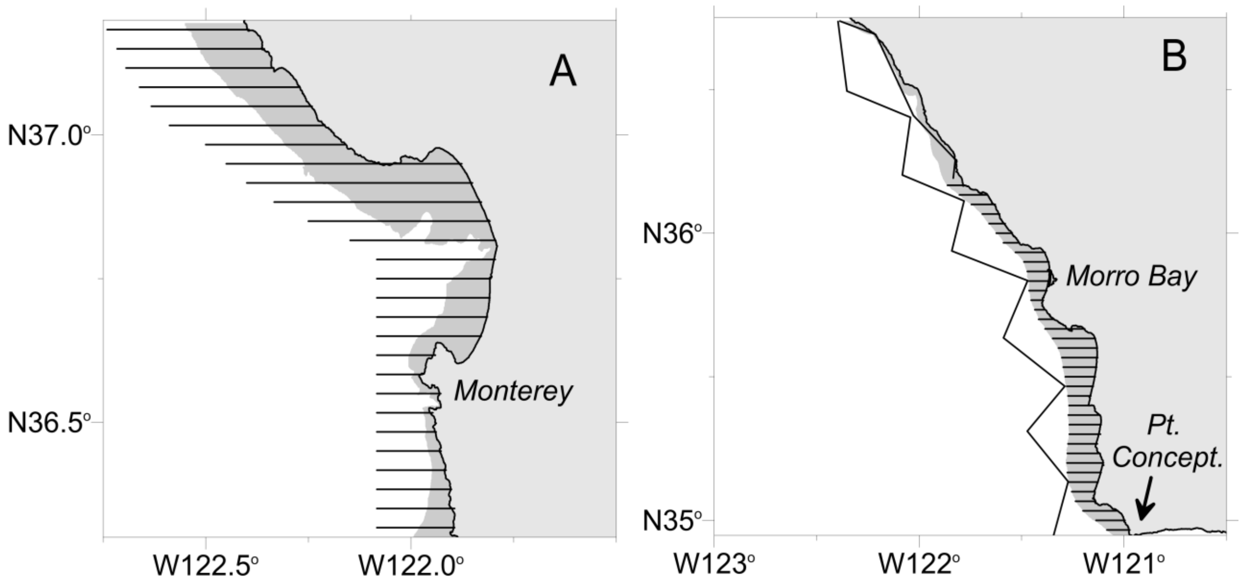

Figure 3. Fine-scale aerial survey transects (black lines) for (A) the Monterey Bay harbor porpoise stock and (B) the Morro Bay harbor porpoise stock. Morro Bay fine-scale transects cover are divided into three strata: Inshore E-W (east-west lines spaced 2 nmi apart), Inshore HPAS, and Offshore Zig-zag transects. Dark gray shading shows inshore stratum.

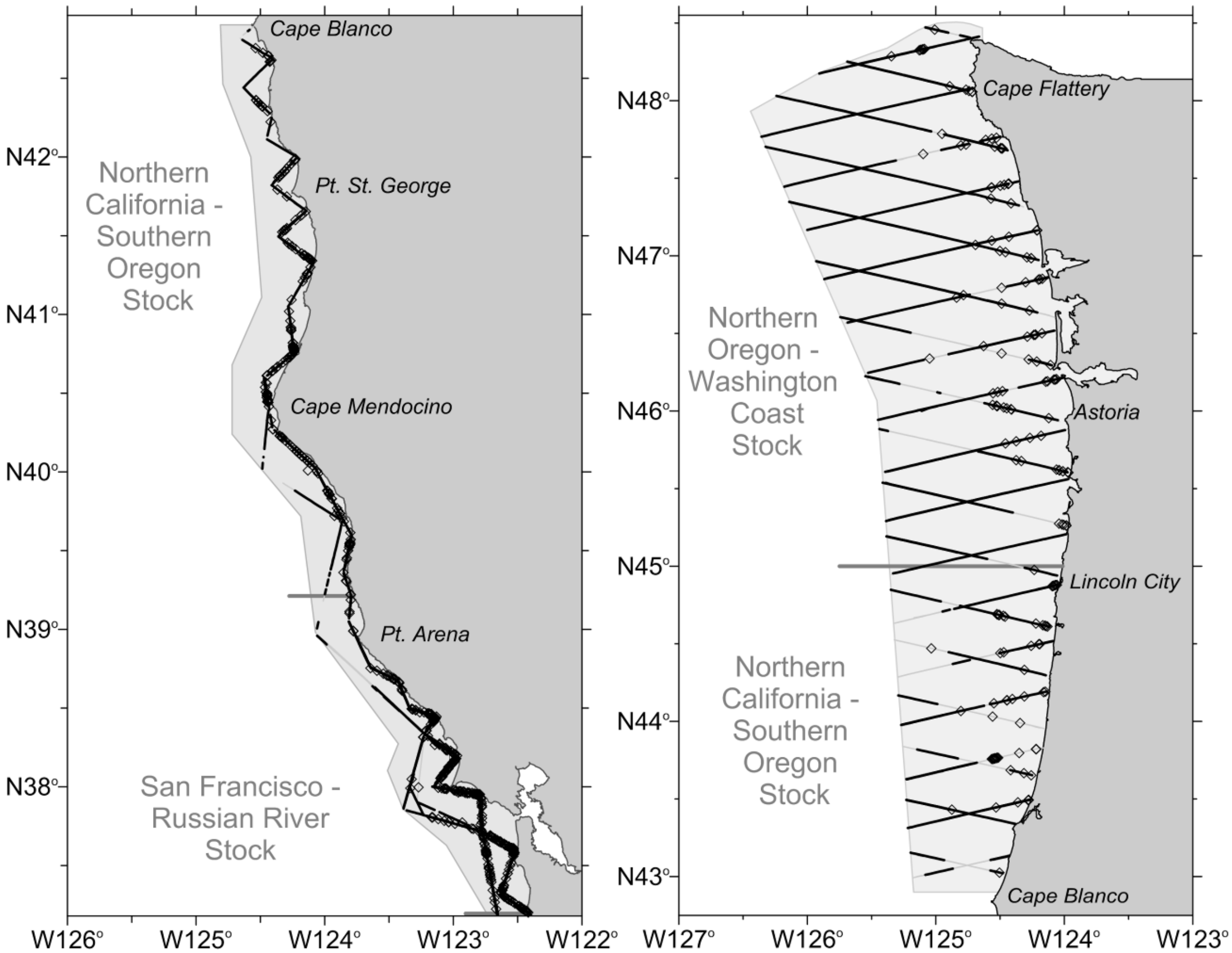

Figure 4. Completed survey transects in excellent sighting conditions (thick black lines) and poor conditions (thin gray lines), and sighting locations (◇) of harbor porpoises during the harbor porpoise aerial surveys (HPAS) and the Oregon/Washington (OR/WA) leatherback surveys. Lines may include multiple overlapping replicates.

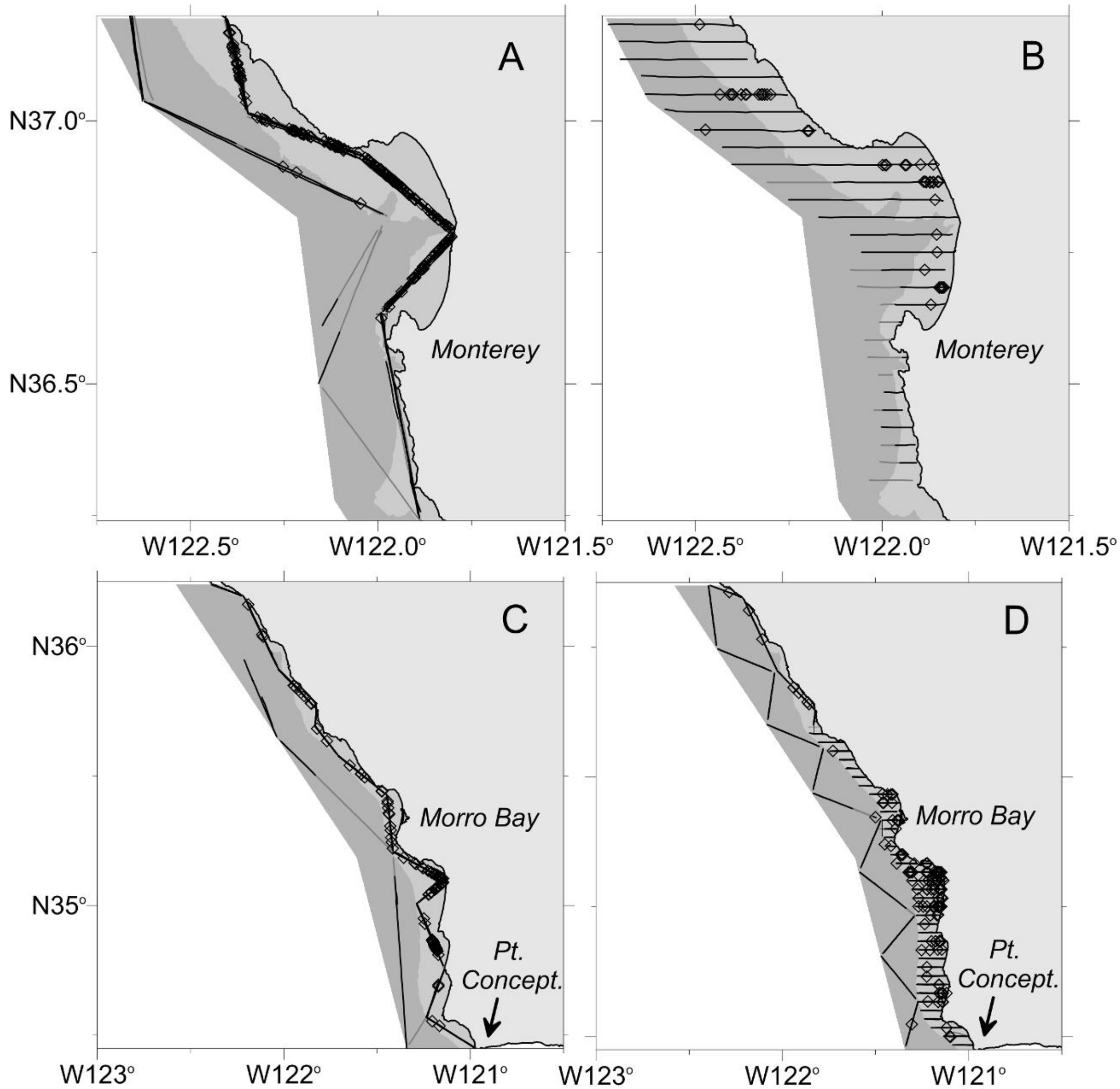

Figure 5. Completed survey transects in excellent sighting conditions (thick black lines) and poor conditions (thin gray lines), and sighting locations (◇) of harbor porpoises during A) Monterey Bay stock harbor porpoise aerial surveys (HPAS); B) Monterey Bay stock fine-scale surveys; C) Morro Bay stock HPAS; and D) Morro Bay stock fine-scale surveys. Lines may include multiple overlapping replicates.

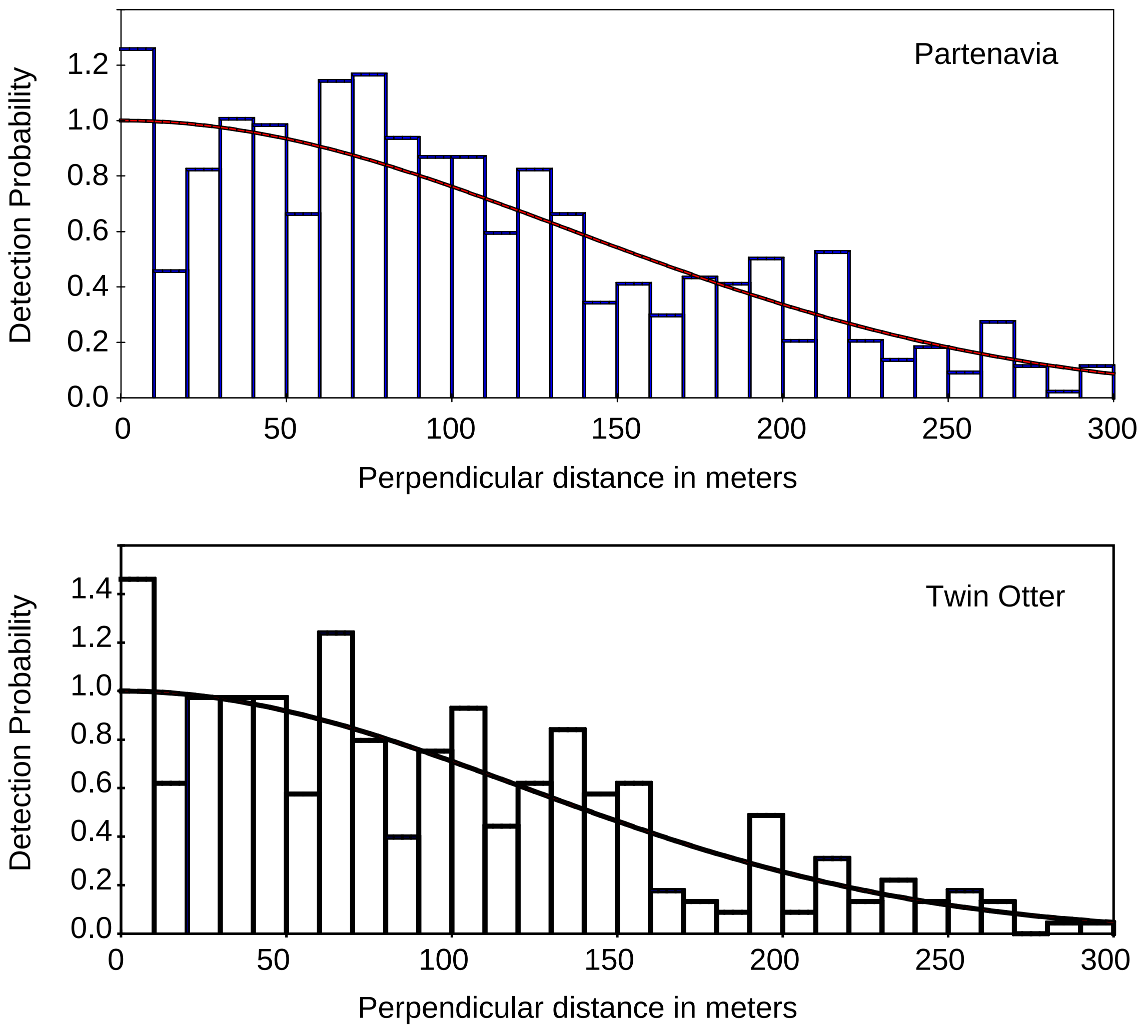

Figure 6. Half normal probability density function fit to perpendicular sighting distances for sightings made from the Partenavia (top; n=723) and Twin Otter (bottom; n=338) aircraft.

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