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U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Marine Fisheries Service
Southwest Fisheries Science Center

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U.S. DEPARTMENT OF COMMERCE
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Preliminary estimates of harbor porpoise abundance in California waters from 2002 to 2007.

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Abstract

The abundance of harbor porpoises in California waters is estimated from aerial line-transect surveys conducted between 2002 and 2007. Surveys were conducted each year during this period, although annual effort varied greatly. Estimated abundance ($\hat{N}$) in four California strata is: **Morro Bay**, $\hat{N}$ = 2,044 (CV = 0.40), **Monterey Bay**, $\hat{N}$ = 1,492 (CV = 0.40), **San Francisco – Russian River**, $\hat{N}$ = 9,189 (CV = 0.38), and **Northern California**, $\hat{N}$ = 14,061 (CV = 0.43). Porpoises in the **Northern California** stratum belong to the **Northern California – Southern Oregon** stock of porpoises. Abundance surveys of the Oregon portion of this stock's range are conducted by the National Marine Mammal Laboratory and will be available at a later date. California stratum estimates are slightly higher than those reported from 1999 to 2002 pooled survey data, with the exception of the Morro Bay stock, which appears to have grown considerably.

Introduction

Four stocks of harbor porpoise are currently recognized in California waters, including one trans-boundary stock with Oregon. The stocks (from south to north) are: (1) **Morro Bay**, from Point Conception to Point Sur; (2) **Monterey Bay**, from Point Sur to Pigeon Point; (3) **San Francisco – Russian River**, from Pigeon Point to Point Arena; and (4) **Northern California – Southern Oregon**, from Point Arena to Lincoln City, Oregon (Figure 1). Stock boundaries are based on lines of evidence from molecular genetic differences (Chivers et al. 2002), pollutant concentration differences (Calambokidis and Barlow 1991), and density minima observed from aerial surveys (Forney 1991; 1995; 1999b). This document presents preliminary estimates of abundance for the **Morro Bay**, **Monterey Bay**, **San Francisco – Russian River**, and the **Northern California** portion of the **Northern California – Southern Oregon** stocks of harbor porpoise from 2002 to 2007 aerial line-transect surveys. Abundance for the entire **Northern California – Southern Oregon** stock will be estimated after results from 2002 and 2003 aerial line-transect surveys in southern Oregon are available. Previous estimates of abundance for these California stocks/strata are presented in Carretta and Forney (2004).

Methods

Harbor porpoise abundance is estimated from 2002 to 2007 summer and autumn aerial line-transect surveys in California waters, using standard line-transect methods (Buckland et al. 2001). Two sets of transects, one inshore (out to the 90 m isobath) and another offshore (out to roughly the 200 m isobath) were surveyed to ensure that all harbor porpoise habitat was included in the surveys. Offshore transects extended to either the 200 m isobath or to a fixed distance offshore (10 nmi south of 37 degrees latitude or 15 nmi north of this latitude), whichever was farther. Surveys were flown at an altitude of 198 m (650 ft) and an airspeed of 165-175 km/hr (90-95 kts). Two observers searched from bubble windows on either side of a twin-engine Partenavia high-wing aircraft, while a third observer searched from a belly port in the rear of the aircraft. One flight in 2007 utilized a similarly configured Twin Otter aircraft and the same methods as were used on the Partenavia aircraft. Sightings were verbally reported to a data recorder who entered sighting and environmental information into a laptop computer receiving real-time GPS input. Further details on the survey methodology and aircraft are found in Forney (1995, 1999). Raw data were error-checked and formatted using a TRUEBASIC program (HPASDIST.TRU). Formatted transect data were then imported in the line-transect software program *Distance 3.5* (Thomas *et al.* 1998), which was used to estimate porpoise density (*D*) and abundance (*N*). Only transect data collected under excellent survey conditions (Beaufort sea state ≤ 2 and cloud cover ≤ 25%) were used in estimating porpoise abundance. The detection function, *f(0)*, was estimated by pooling all sightings from transect segments meeting these environmental criteria. A variety of models (half normal, uniform, hazard rate) were fit to the perpendicular distance data using cosine, hermite polynomial, and simple polynomial series expansions, and the model fit 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 and interval cut points were explored during model fitting. Because observers may fail to detect small groups of porpoises at greater distances, mean group size can be positively biased. For this reason, the group size bias regression method in *Distance 3.5* was used to correct for this bias. This method regresses the natural logarithm of observed group size against estimated *g(x)* and corrected group sizes are estimated by extrapolating the regression to zero perpendicular distance (Thomas *et al.* 1998). The resulting expected group size at zero perpendicular distance is used in this analysis for all inshore strata density and abundance estimates. There were too few offshore strata sightings to correct for group size bias. For comparison, analyses were also done without the group size correction method, using the observed mean group sizes to calculate density and abundance. Porpoise abundance N_i, was estimated for each geographic stratum using the equation

$$\hat{N}_i = \frac{A_i \cdot n_i \cdot f(0) \cdot E(S_i)}{2 \cdot L_i \cdot g(0)} \qquad (1)$$

where

A_i = size of the study area in stratum i (in km^2),

n_i = number of porpoise groups detected in stratum i,

$f(0)$ = probability density function (km^{-1}) evaluated at zero perpendicular distance,

$E(S_i)$ = expected group size in stratum i at zero perpendicular distance,

L_i = length of transect line (in km) surveyed in stratum *i*,

g(0) = probability of detecting a porpoise group on the transect line.

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 the same aircraft type and survey methods as in this study.

Separate estimates of porpoise density and abundance are presented for *inshore* and *offshore* strata within the following California strata: (1) **Morro Bay**, from Point Conception to Point Sur; (2) **Monterey Bay**, from Point Sur north to Pigeon Point; (3) **San Francisco – Russian River**, from Pigeon Point to Point Arena; and (4) **Northern California**, from Point Arena to the California/Oregon border. Combined estimates of porpoise abundance for *inshore* and *offshore* strata are made for each geographic region. Variances of all density estimates and encounter rates were estimated empirically using the software DISTANCE 3.5. Log-normal 95% confidence intervals of abundance estimates were calculated using the Satterthwaite procedure, described in Buckland *et al.* (1993), where

$$\hat{N}_{L95\%} = \hat{N} / C \qquad (2)$$

$$\hat{N}_{U95\%} = \hat{N} \cdot C \qquad (3)$$

and

$$C = \exp\left\{ t_{df\,(0.025)} \sqrt{\log_e\left(1 + \left[cv(\hat{N})\right]^2\right)} \right\} \qquad (4)$$

A coefficient of variation (CV) is calculated for each regional stratum estimate from the pooled inshore (*i*) and offshore transects (*o*), as the square root of the sum of the squared CVs of the group size, encounter rate, detection function, and trackline sighting probability parameters:

$$CV(N_{i+o}) = \sqrt{CV^2(E(S)_{i+o}) + CV^2(\frac{n}{L_{i+o}}) + CV^2(f(0)) + CV^2(g(0))} \qquad (5)$$

The parameters *f(0)* and *g(0)* are common to all strata.

Weather and logistical constraints did not permit even coverage of the transects within each stratum. To account for potential biases that can result from uneven allocation of spatial effort within a stratum, 'weighted' abundance estimates (N_{weight}) that corrected for uneven transect coverage were calculated and compared with unweighted estimates. This was done for inshore strata only, as sparse offshore effort resulted in most offshore transects being surveyed only once in a given year. For weighted estimates, the encounter rates were calculated following the methods described in Benson et al. (2007):

$$\frac{n_i}{L_i} = \sum_{j=1}^{J} \frac{t_{jk}}{T_{jk}} \frac{n_{jk}}{L_{jk}} \qquad (8)$$

where

J = the total number of transects within stratum i;

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

T_{jk} = the total length of all transects in stratum i;

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

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

Weighted abundance estimates are reported in the Results section; these estimates will be used for stock assessment purposes, to reduce the bias associated with uneven spatial survey coverage.

Results

A total of 746 porpoise groups were sighted during 7,932 km of survey effort in Beaufort sea states of 0 through 2 and cloud cover ≤25%. Most survey effort (93%) was conducted in the inshore strata and the remainder in the offshore strata. Survey effort varied considerably by year, with approximately 54% of all effort occurring in 2002 (Figure 2). A half normal detection function provided the best fit ($\chi^2 = 1.086$, df = 3, $p = 0.78$) to the perpendicular sighting distance data, with no truncation (Figure 3). Differences between abundance estimates obtained with and without group size bias corrections were negligible (<2%) and size bias corrected estimates are presented here. Total estimated abundance for California waters out to 200 m is 26,786 (CV = 0.39) harbor porpoise, which is 8.5% higher than the estimate of 24,679 (CV = 0.37) reported by Carretta and Forney (2004) from 1999 and 2002 pooled data. We did not test for statistical differences between these two estimates because the two datasets share common parameters of *g(0)* and for 2002 data, f(0). As in previous years, porpoise abundance was greatest in the **Northern California** and **San Francisco - Russian River** (Table 1). Differences between weighted and unweighted estimates of porpoise abundance differed in magnitude and direction, depending on the stratum (Table 1). Weighted estimates for **Morro Bay** and **Monterey Bay** inshore strata were 9% and 4% lower than unweighted estimates, respectively. Weighted estimates for **San Francisco – Russian River** and **Northern California** inshore strata were 3% and 9% higher than unweighted estimates, respectively (Table 2). This suggests that transects with greater porpoise densities received proportionally greater coverage in the **Morro Bay** and **Monterey Bay** strata, and lower coverage in the two northern strata.

Discussion

Estimates of porpoise abundance presented here are the highest to date for California waters. The Morro Bay stock estimate (*N* = 2,346) is the highest obtained since surveys have been conducted, and it appears that this stock may be recovering from gillnet mortality that reduced its size to a few hundred individuals in the late 1980s (Barlow *et al.* 1988, Barlow and Forney 1994, Forney 1999a, 1999b; as reported in Carretta *et al.* 2007). This would imply a population growth rate between 10 and 15% annually, which is consistent with the median growth rate of 10% reported by Caswell *et al.* (1998) for Atlantic harbor porpoise and high reproductive rates reported for this species by Read and Hohn (1995). Bayesian estimation of harbor porpoise growth rates, using the time series of aerial survey abundance estimates dating back to the late 1980s (Forney 1999a,b; Carretta and Forney 2004; this study), would be useful for parameterizing growth rates for California harbor porpoise stocks in a future study.

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Table 1. Effort summary, line-transect parameters, and porpoise density and abundance estimates by geographic stratum. Corrected estimates of abundance include correction for *g(0)*, the probability of detecting a porpoise on the trackline.

2002-2007	No. of Groups n	Mean Grp Size s	Expect. Grp Size E(s)	Study Area A km2	Transect Length L km	f(0) km-1	Uncorrected Density D km-2	Uncorrected Abundance N	CV	Lognormal Lower 95% C.I.	Lognormal Upper 95% C.I.	Corrected Density D km-2	**Corrected Abundance N**	**CV**	**Lognormal Lower 95% C.I.**	**Lognormal Upper 95% C.I.**
Morro Bay Inshore	119	1.93	1.94	1,851	1,940	5.166	0.308	570	0.16	421	773	0.959	**1,776**	**0.40**	**920**	**4,149**
Morro Bay Offshore	1	1.00		4,335	143	5.166	0.018	78	0.54	27	225	0.062	**268**	**0.65**	**77**	**933**
Morro Bay (All)	120			6,186	2,084	5.166		648		448	998	0.330	**2,044**	**0.40**	**997**	**5,082**
Monterey Bay Inshore	95	1.72	1.69	1,193	1,366	5.166	0.303	361	0.16	267	491	0.999	**1,192**	**0.40**	**583**	**2,632**
Monterey Bay Offshore	2	1.50	1.50	1,997	176	5.166	0.044	88	0.71	22	344	0.150	**300**	**0.80**	**67**	**1,350**
Monterey Bay (All)	97			3,190	1,542	5.166		449		289	835	0.468	**1,492**	**0.40**	**650**	**3,982**
SFO Russian River (Inshore)	373	1.94	1.76	4,800	3,302	5.166	0.515	2,472	0.10	2,052	2,983	1.819	**8,733**	**0.38**	**4,133**	**17,373**
SFO Russian River (Offshore)	1	3.00		4,417	257	5.166	0.030	133	1.34	17	1,031	0.103	**456**	**1.39**	**56**	**3,697**
SFO Russian River (All)	374			9,217	3,559	5.166		2,605		2,069	4,014	0.997	**9,189**	**0.38**	**4,189**	**21,070**
Northern CA (Inshore)	154	1.87	1.64	3,652	671	5.166	0.972	3,549	0.23	2,248	5,615	3.642	**13,302**	**0.44**	**5,344**	**27,708**
Northern CA (offshore)	1	1.00	1.00	6,624	77	5.166	0.033	219	0.59	71	693	0.115	**759**	**0.69**	**205**	**2,812**
Northern CA (All)	155			10,276	748	5.166		3,768		2,319	6,308	1.368	**14,061**	**0.44**	**5,549**	**30,520**
California (All)	746			28,869	7,932		0.259	7,470	0.13	5,125	12,155	0.928	**26,786**	**0.39**	**11,385**	**60,654**

Table 2. Differences in density and abundance estimates obtained with and without transect-weighting. Weighted estimates were made only for inshore strata due to small sample sizes in offshore strata.

Inshore Strata Estimates	Unweighted	Weighted	Difference	% Diff
Morro Bay	1,954	1,776	178	-9.1%
Monterey	1,239	1,192	47	-3.8%
SFO-Russian River	8,473	8,733	-260	3.1%
Northern CA	12,168	13,302	-1,134	9.3%
California (All)	23,834	25,003	-1,169	4.9%

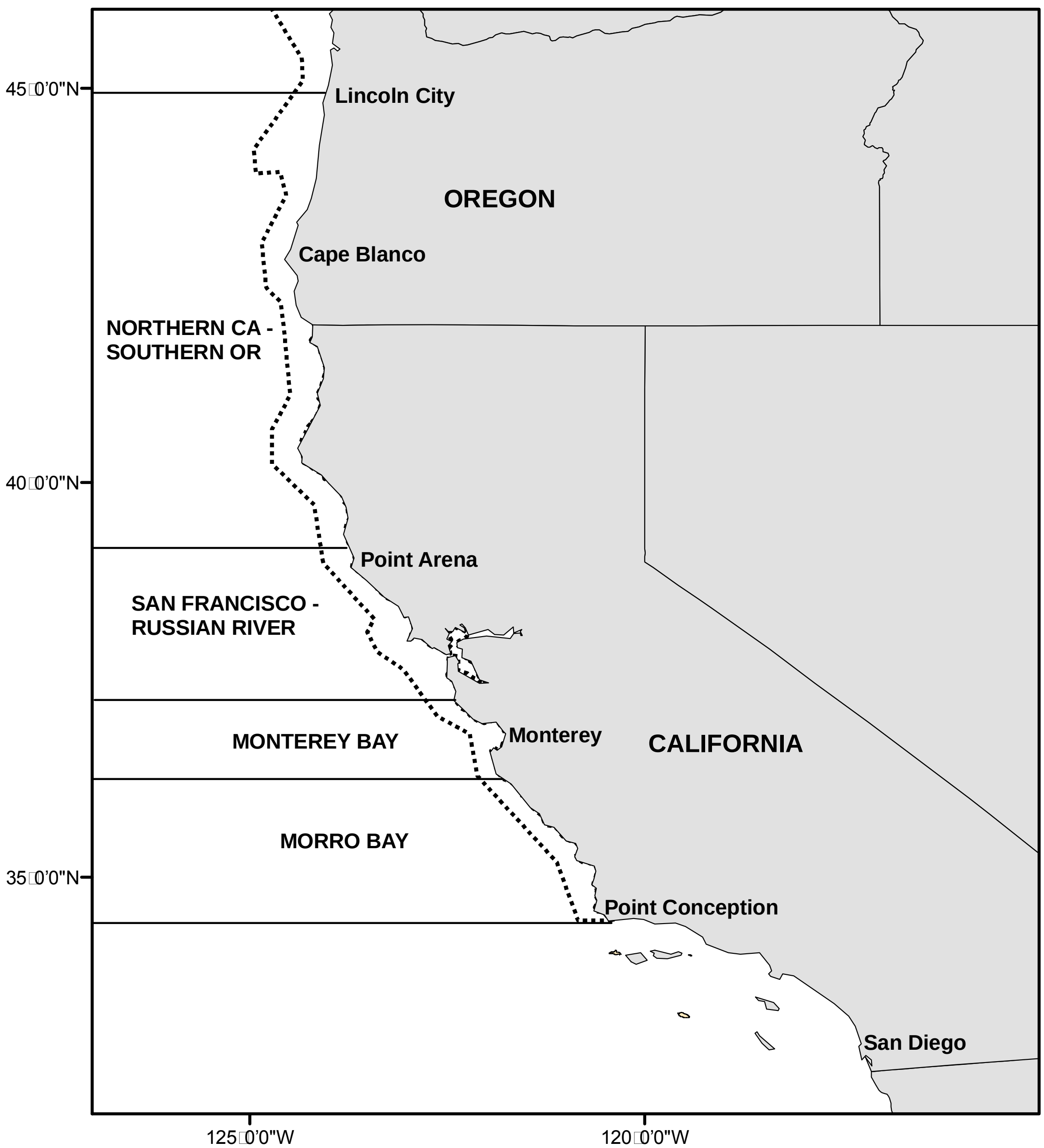

Figure 1. Aerial survey study area, showing harbor porpoise stock names and boundaries, transect lines, (bold), and approximate range of harbor porpoise from shore to 200 m in this region (dashed).

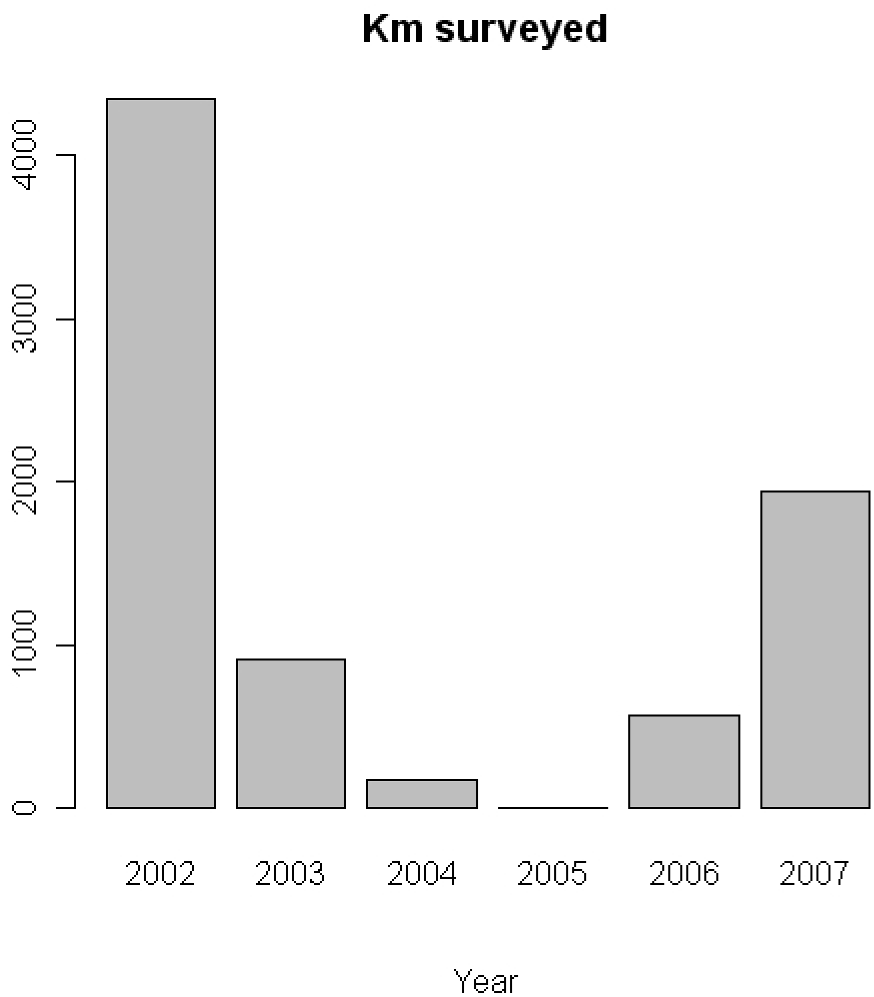

Figure 2. Survey effort in km, by year. A total of 7,932 km were surveyed in Beaufort sea states 0 through 2 and cloud cover ≤25%.

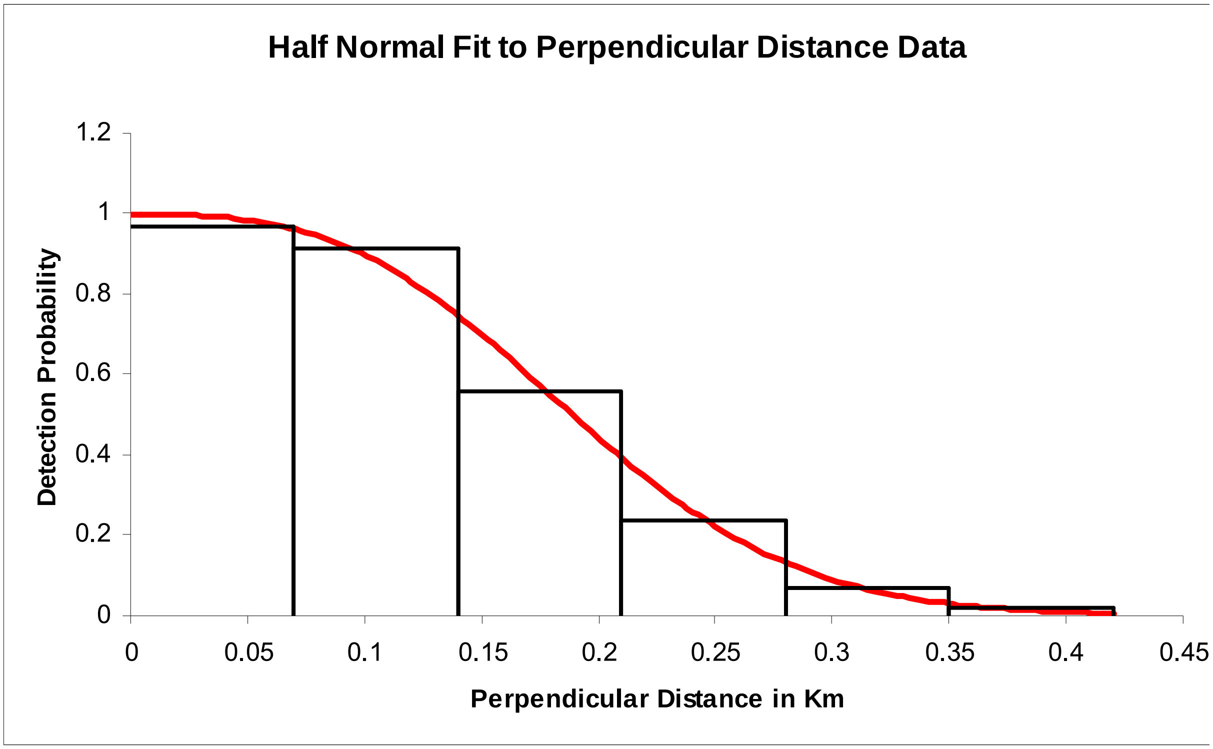

Figure 3. Half normal probability density function fit to perpendicular sighting distances for Beaufort sea states 0 to 2 and cloud cover ≤ 25%. Model fit statistics are *f(0)*=5.16 km^{-1}, χ^2 = 1.086, $p = 0.78$, and the effective strip width (ESW) is 193 m.

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