Line-transect survey of Hector's dolphin abundance between Timaru and Long Point, and effect of attraction to survey vessel

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ABSTRACT

This report summarises results of line-transect surveys to quantify the abundance of Hector's dolphins (*Cephalorhynchus hectori*) in the coastal area between Timaru, East Coast, South Island, and Long Point (12 nautical miles west of Te Waewae Bay), Southland, New Zealand. A total of 27 sightings were made in 437 km of trackline. Greatest dolphin densities were found in Te Waewae Bay, and between Timaru and Oamaru. No sightings were made off the SE coast between Karitane (north of Dunedin) and Colac Bay (west of Bluff), and no sightings were made on any of the offshore transects extending from 4 to 10 nautical miles offshore. Simultaneous boat and helicopter surveys were conducted off the south side of Banks Peninsula to measure the combined effect of dolphins being attracted to the survey vessel and observers missing sightings. Analysis of these data show that uncorrected estimates are inflated by a factor of two. That is, correcting for attraction and missed sightings results in a downward revision of abundance estimates by 50%. The corrected estimate for Motunau–Timaru (to 4 nautical miles offshore) is 1198 (95% CI = 848–1693) and for Timaru to Long Point is 399 (95% CI = 279–570). The total estimate for the Motunau to Long Point coastal area is 1597 (95% CI = 1175–2171).

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1. Introduction

As part of an effort to provide updated, robust data on the population size of Hector's dolphin (*Cephalorhynchus hectori*), two line-transect surveys have now been conducted. The first took place in January and February 1998, covering the area between Motunau to Timaru (see Dawson et al. 2000). In the 1998/99 summer, a further survey extended this coverage from Timaru to Long Point, 12 nautical miles (n.m.) (22 km) west of Te Waewae Bay, on the southeast coast of the South Island, New Zealand (see Figs 1 and 2). This latter survey stopped at Long Point because there were at that time no substantiated records of Hector's dolphins in Fiordland. The Stewart Island coast was not covered for the same reason.

The principal justification for these surveys was that the only previous quantitative population estimate for Hector's dolphins (Dawson & Slooten 1988) is now more than a decade old. The recent discovery of genetically different sub-populations of Hector's dolphins (Pichler et al. 1998) and results of recent modelling of extinction risk (Martien et al. 1999) highlight the need for updated, fine-grained information on the distribution and abundance of Hector's dolphins.

Methods employed in the recent line-transect surveys are specifically adapted to suit surveying Hector's dolphin, which favours inshore waters, and is often found within a few hundred metres of shore (Dawson & Slooten 1988). Conventional vessels used in line-transect surveys (e.g. Barlow 1988) are inappropriate for this application due to prohibitive daily cost and restricted ability to work in shallow water. Hence we adapted standard line-transect survey methods (e.g. Barlow 1988) for use on a privately owned 15 m catamaran. This vessel (RV *Catalyst*) is equipped with a purpose-built observer platform giving an eye height of 6 m. *Catalyst* has a cruising speed of 9–10 knots (at <14 litres of diesel/hr), and a safe minimum working depth of 2 m.

The Motunau to Timaru survey proved the suitability of the methods and survey design, but highlighted the problem of responsive movement by the dolphins. Orientation data showed that dolphins, when first seen, were usually heading towards the vessel, indicating strong attraction. In addition, an extensive set of zig-zag photo-ID surveys of Hector's dolphins in Akaroa Harbour (Banks Peninsula) suggested that the uncorrected line-transect estimate was inflated (Dawson et al. 2000).

Buckland & Turnock (1992) presented a method to use coordinated boat and helicopter surveys to quantify the combined effects of vessel attraction and sightings that were missed by vessel observers. They then applied it to studies of Dall's porpoise abundance, showing that uncorrected surveys may overestimate abundance by up to five times (Turnock et al. 1995). The helicopter method allows sightings to be made much further ahead of the vessel than a dual platform approach (e.g. Palka 1995), and far beyond the visual range of any vessel observer. The method ensures that the two sighting teams are totally isolated from each other, and provides more certainty that dolphins are sighted before they respond to the vessel. For these reasons we adapted Buckland & Turnock's (1992) approach in our trials of 1998/99.

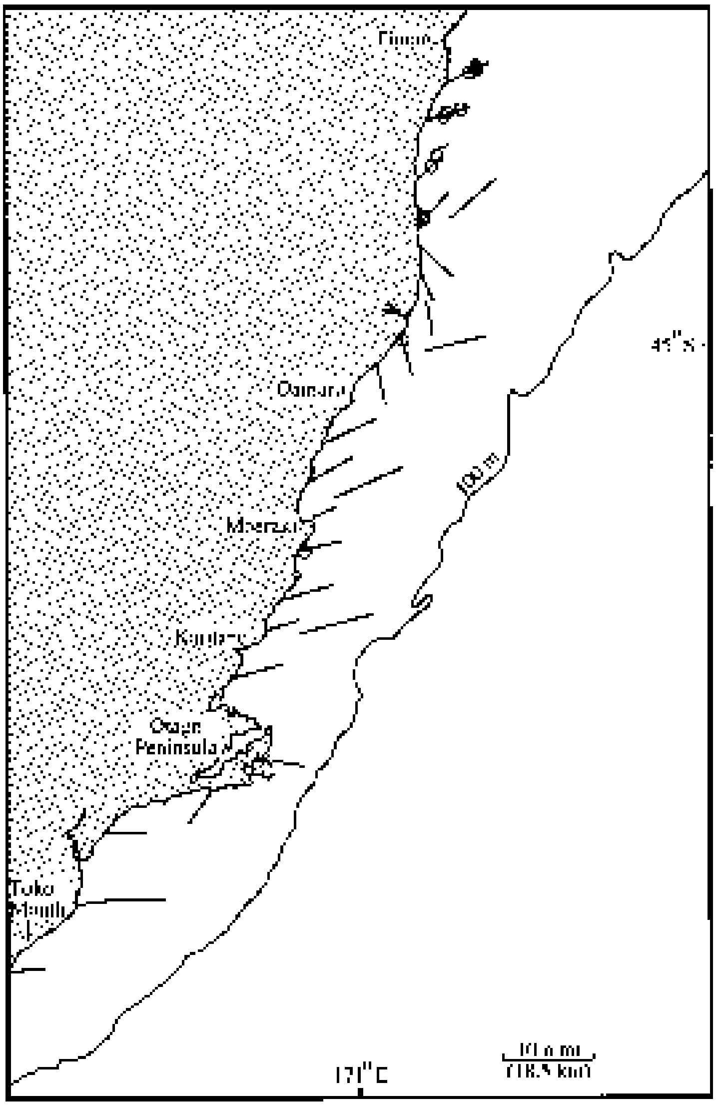
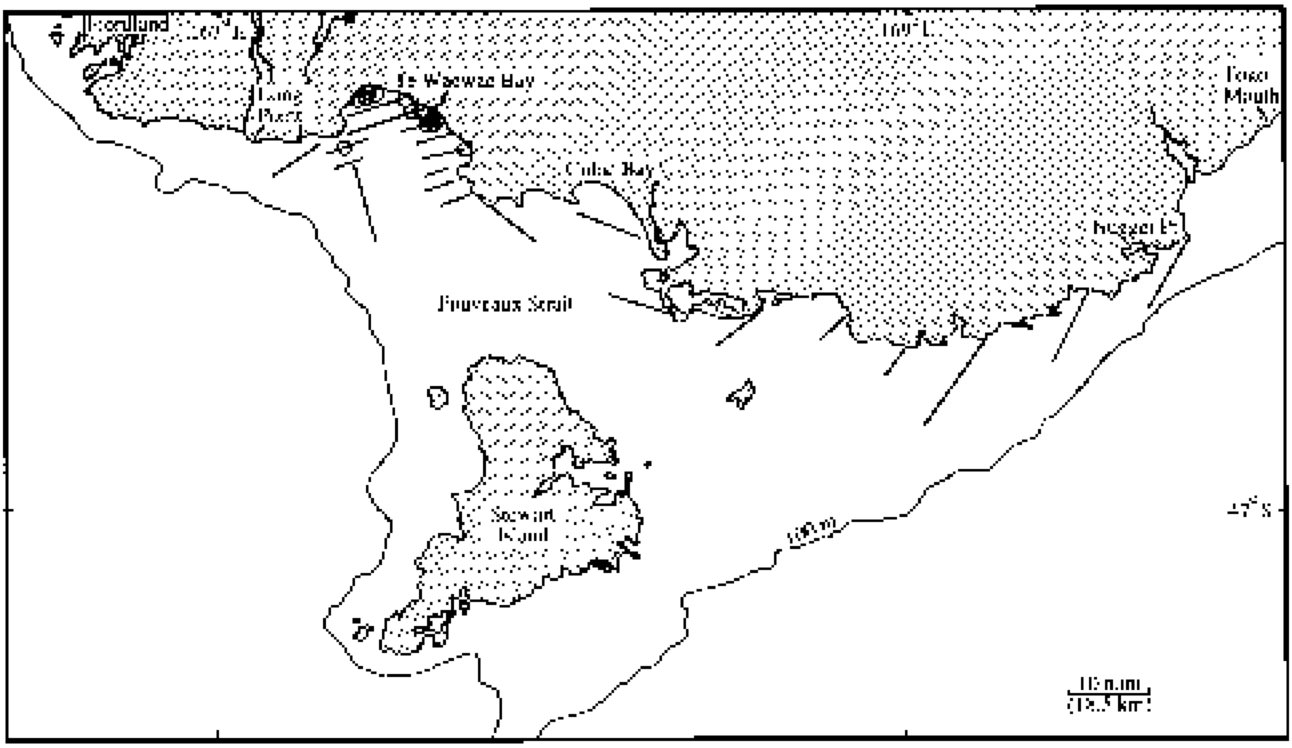


Figure 1. Transect lines and sightings between Timaru and Nugget Point.

Figure 2. Transect lines and sightings between Nugget Point and Long Point.



2. Field methods

2.1 TIMARU-LONG POINT LINE TRANSECT SURVEY

Survey methods were essentially the same as for the Motunau-Timaru survey (Dawson et al. 2000).

Three observers were used at any one time, one each looking left and right and one in the centre acting as recorder, entering sighting information into a palmtop computer. The left and right observers used seven power binoculars to minimise the effect of reactive movement by the dolphins before detection. Observer tasks were rotated at least every 30 minutes to avoid fatigue. Sightings were entered in real time on a computer on the sighting platform. This computer was linked to *Catalyst*'s GPS navigator.

Fujinon 7 × 50 marine binoculars with in-built reticle scales and compass were used to measure the downward angle from the land, or horizon, to the sighting, and the angle between the boat's trackline and the sighting. The nearest ferrous metal fittings are more than 4 m from the aluminium observer platform and were therefore unlikely to influence compass bearings. The corresponding distance to land was measured using RADAR (Furuno 16 mile), or, if within a few hundred metres of shore, with a Bushnell Lightspeed laser rangefinder (accuracy ± 1 m from 12 to 800 m). We measured the accuracy of the RADAR by comparison with transit fixes and laser rangefinder measurements, and applied this correction to all RADAR measurements.

A 12 channel GPS Chartplotter (Cetrek 343) was used for navigation. This system used digitised (C-MAP) charts onto which we laid out all transect lines. It also fed latitude, longitude, and date/time data to the computer on the sighting platform. The custom-written program running on this computer (Hewlet-Packard 200LX) used these data to record sighting effort, and allowed input of sighting data including sighting angle, reticles, group size, orientation of the animals when first sighted, depth, Beaufort sea state, swell height and glare.

Design principles were also the same as in our previous survey, with all transect lines being placed at 45° to the coast (see Figs 1 and 2). Inshore lines between Timaru and Otago Peninsula were spaced at 4 n.m. Lines between Timaru and Long Point were spaced at 8 n.m., while lines within Te Waewae Bay were spaced at 2 n.m. These relative spacings reflected densities seen in the 1984/85 survey (Dawson & Slooten 1988). Offshore transects were spaced at approximately 40 n.m. (1 for every 4-5 inshore lines).

On open coasts we minimised pitching (fore and aft) movement of the vessel by running all transect lines down-swell. Additionally, we restricted survey effort to sea conditions of Beaufort 3 or less, and swell heights of <1.5 m.

Observer training was conducted on 10 days, during which more than 100 sightings were made. This intensive training was done for two reasons. Firstly, the Motunau-Timaru survey showed that at least a week, and preferably two, of observer training was required to ensure high data quality. Secondly, it was important to ensure that the scanning behaviour of the current observer crew was as close as possible to that of the previous survey. This was necessary because the correction factor developed from the helicopter trials (described below) was applied to data collected during both surveys.

2.2 HELICOPTER TRIALS

Helicopter trials were carried out to the south of Banks Peninsula, predominantly between Birdlings Flat and the mouth of the Rakaia River. This area was chosen because it displayed representative and varying densities, and because it was sheltered from the prevailing north-easterly winds. Most transects were run parallel to the coast to avoid the very high densities that are often encountered when approaching the shore. A small amount of surveying was also carried out in Akaroa Harbour.

A Robinson R22 helicopter with pilot and one observer (ES) followed a zig-zag flight path approximately 1.5 km in front of the boat, travelling out to 1000 m either side of the vessel's trackline (Fig. 3). To aid tracking sightings from the

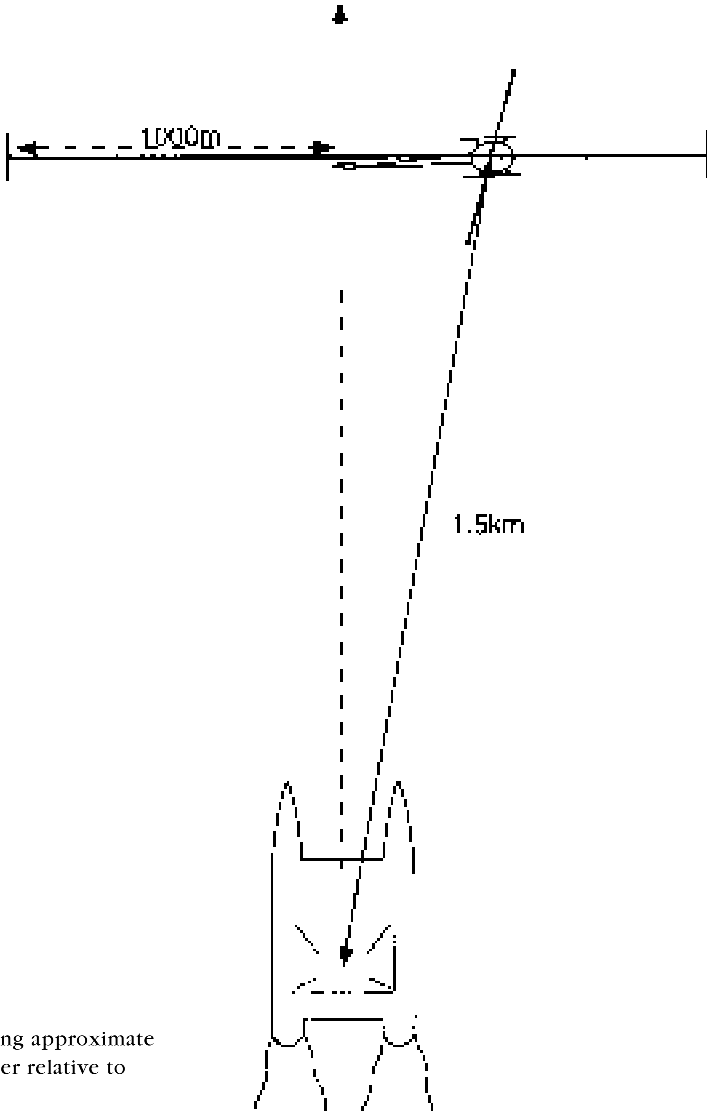


Figure 3. Diagram showing approximate flight path of the helicopter relative to the survey vessel.

air, sighting positions were marked with rhodamine dye bombs. The position of the helicopter relative to the boat was determined via the boat's RADAR (Furuno 1720). The absolute position of the boat was determined to an accuracy of 2–5 m via differential GPS (Trimble GeoExplorer; post-processed). Land distances (required for calculation of sighting range calculation) were obtained at the time of sighting via RADAR or during analysis using GIS coastline data and the computer program 'SDR Map'.

Boat observers followed standard sighting procedures (see above) using Fujinon 7 × 50 marine binoculars with in-built compasses and reticle scales. If these observers' attention was drawn to dolphin groups by the position of the helicopter, the results of these trials could be biased. To minimise the cues available from the helicopter, we instructed the pilot to occasionally fly as if he had a sighting, when he did not. Further, on most occasions the problem did not arise because the helicopter was well above the field of view of the observers' binoculars. When it was within view, observers made a conscious effort to remain unbiased by the movements of the helicopter. The fact that a number of dolphins that were sighted by helicopter subsequently passed within a couple of hundred metres of the boat without being seen by the boat observers suggests that efforts to avoid bias were successful.

On making a sighting, the helicopter observer informed an independent observer located in the cabin of the boat (all communications went via the independent observer—at no stage could boat observers hear the helicopter observer or vice versa). The helicopter then hovered directly above the sighting while a range and bearing relative to the boat was taken via RADAR. The helicopter then ceased hovering, but tracked the sighting either until the boat observers had sighted the group, or it had passed abeam of the boat. A second range and bearing were then taken. Sightings that were lost during tracking were discarded during analysis. The independent observer, in liason with the helicopter observer and boat observers, determined whether the sighting was a duplicate (i.e. made by both helicopter and boat observers) using information on location and group size. These decisions were double-checked in analysis by inspection of the plotted locations of sightings made from either or both platforms.

3. Data analysis

3.1 TIMARU–LONG POINT ABUNDANCE ESTIMATES

Conventional abundance estimates were calculated using standard line-transect procedures. These were later corrected to produce unbiased abundance estimates that accounted for both vessel attraction and missed groups.

Within each stratum, Hector's dolphin abundance (N_s) was estimated as

$$N_s = \frac{A\,n\,s}{2\,L\,ESW} \tag{1}$$

where: A = size of the study area,
n = number of groups seen,
s = expected group size,
L = length of transect line surveyed,
ESW = the effective half strip width.

Sizes of the various strata were measured from nautical charts using a digital planimeter. The area of each stratum was measured several times to ensure accuracy.

Expected group size was estimated as a simple mean group size.

Using the program Distance 3.5 (Thomas et al. 1998), a half-normal function with cosine adjustments was fitted to perpendicular distance data to estimate effective strip width *ESW* (note that this value is derived directly from *f(0)*, described in section 3.2). Akaike's Information Criterion was used to select among models fitted to the data (models were: hazard/cosine, hazard/polynomial, half-normal/hermite, half-normal/cosine, uniform/cosine). Perpendicular sighting distances were truncated at 640 m and binned manually for *f(0)* estimation.

The coefficient of variation (CV) for the abundance estimate was calculated from the coefficients of variation of each variable element in equation 1 above:

$$CV(N_S) = \sqrt{CV^2(n) + CV^2(s) + CV^2(ESW)} \qquad (2)$$

The *CV(n)* was estimated empirically as recommended by Buckland et al. (1993):

$$CV(n) = \sqrt{\frac{\mathrm{var}(n)}{n^2}} \qquad (3)$$

where:

$$\mathrm{var}(n) = L \sum l_i (n_i/l_i - n/L)^2/(k-1) \qquad (4)$$

where: l_i = the length of transect line i,
n_i = the number of sightings on transect i, and
k = number of transect lines.

The *CV(s)* was estimated from the standard error of the mean group size. The *CV(ESW)* was estimated via Distance's bootstrapping option. This process incorporates uncertainty in model fitting and model selection.

3.2 HELICOPTER TRIALS

To calculate the correction factor, data were analysed following Buckland & Turnock (1992). Let

$g_s(y)$ = probability that a group detected from the helicopter at perpendicular distance y from the trackline of the ship is subsequently detected from the ship,

w = truncation distance for perpendicular distances y,

$f_s(y) = g_s(y)/\mu$, with $\mu = \int_0^w g(y)dy$

n_h = number of helicopter detections,

n_s = number of ship detections,

n_{hs} = number of detections made from both platforms (duplicate detections),

$f_h(y)$ = probability density function of helicopter detection distances,

$f_{hs}(y)$ = probability density function of duplicate detection distances as recorded from the helicopter,

$f(x)$ = probability density function of perpendicular distances recorded from the ship,

L = length of transect line.

A conventional estimate of density of groups, assuming no responsive movement and $g(0) = 1$ (all animals on the trackline seen with certainty) is calculated as:

$$\hat{D}_S = \frac{n_s \hat{f}(0)}{2L} \tag{5}$$

A corrected estimate, allowing for responsive movement and including an estimate of $g(0)$ is given by

$$\hat{D}_U = \frac{n_s \hat{f}_s(0)}{2L \hat{g}(0)} \tag{6}$$

Where

$$\hat{f}_s(0) = \frac{\hat{g}_s(0)}{\int_0^W \hat{g}_s(y)dy} \tag{7}$$

and

$$\hat{g}_s(y) = \frac{n_{hs} \hat{f}_{hs}(y)}{n_h \hat{f}_h(y)} \tag{8}$$

The parameters $f_{hs}(y)$ and $f_h(y)$ were estimated using standard line-transect methods, with a common truncation distance of w. A correction factor for abundance estimates of Hector's dolphin groups can be estimated by

$$\hat{c} = \hat{D}_U / \hat{D}_S \tag{9}$$

Using Distance 3.5 (Thomas et al. 1998) a half-normal model with cosine adjustments was used to estimate $f(0)$. The half-normal model was fitted to helicopter data to estimate $f_h(0)$ and the uniform model with cosine adjustments was used to estimate $f_{hs}(0)$. All were selected using Akaike's Information Criterion. Potential model choices were hazard/cosine, hazard/polynomial, half-normal/cosine, half-normal/hermite and uniform/cosine. Truncation distance was 640 m for boat sightings, and 1000 m for helicopter and duplicate sightings. Sightings for which range (radial distance) was estimated by eye, and those made during Beaufort sea state >2, were removed before $f(0)$ estimation, but were used for density estimation. Surveys were discontinued when sea state rose above Beaufort 3. These criteria were used to ensure that only high quality data were used to estimate effective half search widths. When sea-state is high, dolphins will be harder to spot at distance. More importantly, those that are seen are likely to have moved further from their original location, therefore biasing estimation of effective strip width. Further, analysis of data collected during the first boat survey (Dawson et al. 2000) indicated that without significant training, observers tended to underestimate distances. This would also bias the effective strip width.

Errors for the uncorrected density estimate were calculated using standard procedures (see Dawson et al. 2000). The error for c was estimated by bootstrapping on legs of effort (transect lines) and applying the estimation procedure to each of 199 bootstrap data sets. The standard deviation of the bootstrap estimates was used as the standard error of c.

Ideally, the correction factor would be estimated separately for each survey from separate sets of boat/helicopter trials conducted in areas of representative density. Financial and logistical constraints prevent this, so the correction factor estimated here was applied to abundance estimates from the 1998 Banks Peninsula survey as well as the 1999 Timaru–Long Point survey.

Unbiased abundance estimates were calculated by

$$\hat{N}_U = \hat{c}\,\hat{N}_S \tag{10}$$

The CVs of the corrected abundance estimates (N_U) were estimated by

$$CV(\hat{N}_U) = \sqrt{CV(\hat{c})^2 + CV(\hat{N}_S)^2} \tag{11}$$

where $$CV(\hat{c}) = \frac{SE(\hat{c})}{\hat{c}} \tag{12}$$

Upper (N_U) and lower (N_L) 95% confidence intervals for N_U were calculated using the Satterthwaite degrees of freedom procedure outlined in Buckland et al. (1993). This procedure assumes a log-normal distribution, using:

$N_L = NLC$, and (13)

$N_U = N\,C$ (14)

where

$$C = \exp\left\{ t_{df}(0.025)\,\sqrt{\log_e(1 + \left[CV(\hat{N}_U)\right]^2)} \right\} \tag{15}$$

The Satterthwaite degrees of freedom (df) for corrected abundance estimate confidence intervals were calculated by

$$df = \frac{CV(\hat{N}_U)^4}{\dfrac{CV(\hat{c})^4}{B-1} + \dfrac{CV(\hat{N}_S)^4}{df_S}} \tag{16}$$

where B is the number of bootstrap samples, and df_S is the Satterthwaite degrees of freedom for the uncorrected abundance estimate, N_S. The Satterthwaite degrees of freedom (df_S) were calculated by

$$df_S = \frac{\{CV(N_S)\}^4}{\dfrac{\{CV(n)\}^4}{k-1} + \dfrac{\{CV(ESW)\}^4}{n}} \tag{17}$$

(see Buckland et al. 1993 for detailed explanation of this procedure).

4. Results

4.1 CORRECTION FACTOR—HELICOPTER TRIALS

Results are summarised in Table 1. The effective half strip width for boat sightings was calculated as 268 m. This is very similar to estimates from the 1998 Banks Peninsula survey (275 m and 264 m for 'harbours and bays' and 'all other strata' respectively, see Dawson et al. 2000). The density (groups/km^2) seen during the helicopter trials was similar to that seen in the same area during the 1998 survey. These results confirm that our field methods were robust to different observer teams.

TABLE 1. SUMMARY OF DENSITY AND CORRECTION FACTOR ESTIMATES (HELICOPTER TRIALS).

Length of transect, L (km)	308
Truncation distance, w (km)	1.0
Number of helicopter detections, n_h	58
Number of ship detections, n_s	126
Number of duplicate detections, n_{hs}	33
Half-ESW of helicopter (km)	0.532
Half-ESW for duplicates (km)	0.342
Apparent half-ESW of boat (km)	0.268
Apparent density estimate (groups/km^2)	0.7631
Corrected density estimate (groups/km^2)	0.3839
Boat detection probability 'near' trackline	0.8861
Correction factor	0.5032
Standard error, SE(c)	0.0912

Detection functions for boat and helicopter sightings (Figs 4 and 5 respectively) are tidy in comparison with those presented in Turnock et al. (1995). The detection function for the duplicate sightings (Fig. 6) was more difficult to fit. Given the restricted sample size of duplicates (n = 33) this is not unexpected. Although the distribution of perpendicular distances looks almost bimodal, this is likely to be an artefact of sample size, rather than any effect of, say, sea state.

Our estimate of *g(0)* (0.89) is high compared with published estimates for harbour porpoises (see Barlow 1988, and Palka 1995). Harbour porpoises are cryptic, and avoid survey vessels (Palka & Hammond 1998; S. Dawson and E. Slooten, pers. obs.), so *g(0)* in their case is expected to be low. The correction factor derived from our helicopter trials is 0.5032. This means that, if left uncorrected, line-transect abundance estimates of Hector's dolphins would be over-estimated by a factor of two.

Figure 4. Sightings v. distance and fitted detection function for boat sightings (half-normal/cosine, n = 121, goodness of fit $c^2 = 0.982$).

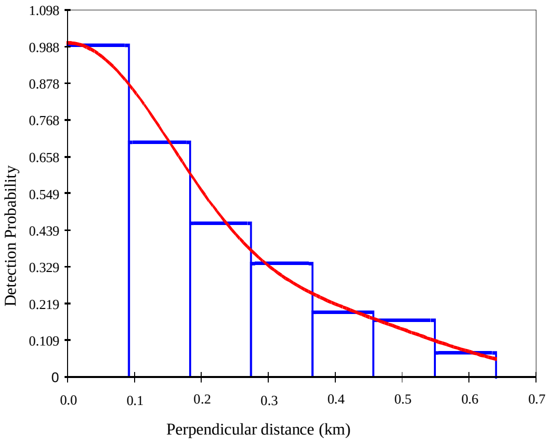


Figure 5. Sightings v. distance and the fitted detection function for helicopter sightings (half-normal, n = 58, goodness of fit $c^2 = 0.732$).

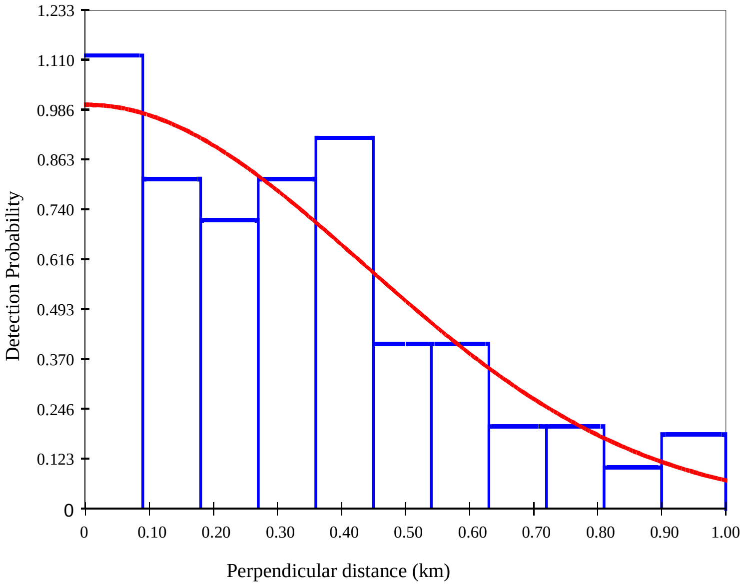
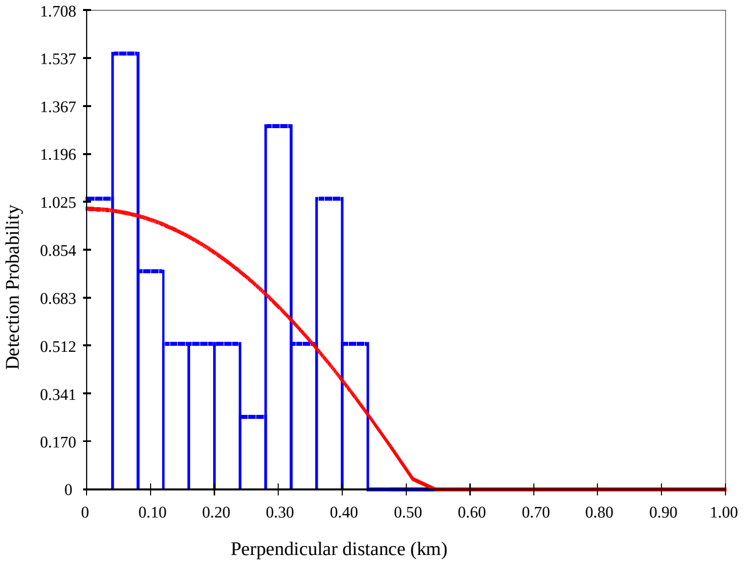


Figure 6. Sightings v. distance and the fitted detection function for duplicate sightings (uniform/cosine, n = 33, goodness of fit $c^2 = 0.085$).



4.2 ABUNDANCE ESTIMATES FOR 1999 TIMARU-LONG POINT SURVEY

There were insufficient sightings to estimate effective strip width robustly (Table 2) using only the 27 sightings gained between Timaru and Long Point (see Figs 1 and 2). Since boat-based sighting procedures were identical, and sighting conditions similar, shipboard sightings made during the helicopter trials at Banks Peninsula were also used for calculation of effective strip width. Seventeen sightings made during Beaufort 3 conditions (perpendicular distances ranged from 0 to 400 m), and 9 sightings with estimated distances were removed (see methods)- this represents approximately 17% of the total sightings. This resulted in a sample size of 121 observations after truncation. This exceeds Buckland et al.'s (1993) recommendation of 60-80 sightings for robust fitting of the detection function by a factor of almost two.

TABLE 2. SURVEY EFFORT AND SIGHTINGS (TIMARU-LONG POINT).

	SURVEY EFFORT (km)	NO. OF SIGHTINGS	SIGHTINGS/km
Timaru-Long Point	336	13	0.04
Te Waewae Bay	101	14	0.14

Because only one sighting was made between Oamaru and Te Waewae Bay, only two levels of stratification for abundance estimates were warranted: Timaru-Long Point, and Te Waewae Bay. A summary of abundance estimation calculations for these strata is given in Table 3. Again, errors include uncertainty in the correction factor.

Corrected abundance estimates from the 1998 Motunau-Timaru survey (originally presented in Dawson et al. 2000) are given in Table 4. Estimates of precision have been recalculated to include the precision of the correction factor. Table 5 contains a combined abundance estimate for the area surveyed so far (Motunau-Long Point).

TABLE 3. ABUNDANCE ESTIMATES (TIMARU-LONG POINT).

	NUMBER OF GROUPS SEEN	EFFECTIVE HALF STRIP WIDTH (m)	ESTIMATED ABUNDANCE, N_U (CORRECTED)	%CV(N_U)	LOWER 95% CONFIDENCE INTERVAL	UPPER 95% CONFIDENCE INTERVAL
Timaru-Long Point	13	268	310	28.39	201	478
Te Waewae Bay	14	268	89	32.40	36	218
Study Area	27	268	399	25.54	279	570

TABLE 4. SUMMARY OF CORRECTED ABUNDANCE ESTIMATES FROM 1998 MOTUNAU-TIMARU SURVEY.

	N_S	N_U	%CV(N_U)	LOWER 95% CI	UPPER 95% CI
Akaroa Harbour	124	62	33.89	40	97
Other harbours	29	14	67.42	5	44
Sanctuary (excl. harbours)	1631	821	22.06	619	1087
Sanctuary (total)	1784	897	28.20	628	1283
Motunau-Timaru (excl. Sanctuary)	597	300	36.46	176	514
Study area total (excl. offshore)	2395	1198	27.26	848	1693

TABLE 5. ABUNDANCE ESTIMATE (MOTUNAU-LONG POINT).

ESTIMATED ABUNDANCE, N_U (CORRECTED)	%CV(N_U)	LOWER 95% CI	UPPER 95% CI
1596	24.13	1175	2171

5. Discussion

Adaptation of the Buckland & Turnock (1992) method for simultaneous boat/helicopter surveys proved straightforward. We made a number of modifications to increase precision (e.g. post-processed GPS to gain position accuracies of 2–5 m) and practicality. In place of a 4+ seat turbine-driven helicopter, we used a Robinson R22, a two-seater piston-engine helicopter. This decision was taken for two reasons. Firstly, since the helicopter can track only one sighting at a time, there is little point in using several observers in it. Secondly, the Robinson was much less expensive to hire, meaning that we could afford to fly more hours to increase the sample size of duplicate sightings. It is important to realise that the analysis does not assume that the helicopter observer is able to spot all dolphins visible at the surface. Instead, it treats each sighting made from the helicopter as a trial or ‘test’, which is then either passed or failed by the boat crew (i.e. they see the same group or do not). The effective strip width of the two platforms is then also compared.

The corrected estimates of abundance are consistent with existing knowledge. In our report of the Motunau–Timaru survey (Dawson et al. 2000) we mentioned that counts made on only three of 115 zig-zag surveys of Akaroa Harbour between 1985 and 1997 fell within the 95% CI of the uncorrected line-transect estimate for the harbour (85–181), suggesting that the line-transect estimate was biased high, perhaps by as much as 40%. The helicopter trials demonstrated that uncorrected surveys would be biased high by 50%. Further, the 1984–85 strip transect survey estimated abundance for the Motunau to

Timaru area (to 5 miles offshore) at 832 (95% CI 689–994; data as reported in Dawson & Slooten 1988, confidence intervals calculated by bootstrapping). The 1998 uncorrected line-transect estimate for this region was 2395 (95% CI = 1802–3183). The 1984/85 survey used considerably different techniques, but provides some basis for comparison. The survey was carried out at approximately the same time of year as the 1998 line-transect survey, so seasonal changes in distribution would be unlikely to account for differences. Since Hector's dolphins in the Banks Peninsula area are known to have small summer home ranges (mean alongshore range = 31 km; Bräger 1998) it is also unlikely that migration would account for differences in the two estimates.

If accepted at face value, this new estimate implied either that the 1984/85 survey result was biased low, or that this population of Hector's dolphins was growing at 7.8% p.a. Dolphins in general appear to have maximum population growth rates from 2 to 4% (Perrin & Reilly 1984; Reilly & Barlow 1986). The population parameters of Hector's dolphins have been studied in detail (Slooten 1991; Slooten & Lad 1991; Slooten et al. 1992; Cameron et al. 1999) and are better known than for most dolphin species. Leslie matrix population models suggest maximum population growth rates of 1.8–4.9%, with 4.9% being the absolute upper bound and 1.8% being the most likely (Slooten & Lad 1991). The 1984/85 survey data from Motunau to Timaru, and the corrected line-transect estimate from 1998 are not significantly different (their 95% confidence intervals overlap). If both are taken at face value, they suggest an annual population growth rate of 2.8%. This estimate is relatively high, but within the range of what could be possible biologically.

6. Acknowledgements

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