Line-transect survey of Hector's dolphin abundance between Motunau and Timaru

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Abstract

Methods and results of the first boat-based line-transect survey in New Zealand waters are reported. The survey was designed to quantify Hector's dolphin (*Cephalorhynchus hectori*) abundance between Motunau and Timaru, East Coast, South Island, out to 4 nautical miles from shore. Greatest dolphin densities were found in Akaroa Harbour, along Birdlings Flat (between Banks Peninsula and the Rakaia River) and off the eastern side of Banks Peninsula. Analyses suggest that overall abundance in the survey area is around 2400 animals (CV=22%). A preponderance of dolphin sightings in which orientation was towards the vessel indicates attraction to the vessel, at least within a radial distance of 400 m. This would lead to an overestimate of abundance. A comparison of the Akaroa Harbour abundance estimate (124, 95% CI 69–222) with previous survey work indicated that estimates may have been biased high. The results from just three of 115 small boat surveys of Akaroa Harbour fall within the uncorrected 95% confidence limits, and the average summer abundance seen on these surveys was 43 (95% CI 34–52). Quantifying the effect of attraction on abundance estimates should be an important objective of further survey work on this species.

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1. Introduction

During January and February 1998, a line-transect survey was carried out between Motunau and Timaru (Fig. 1) to estimate abundance of Hector's dolphins (*Cephalorhynchus hectori*). The principal justification for the survey was that the only quantitative abundance estimate for Hector's dolphins (Dawson & Slooten 1988) is now more than 10 years old. It is no longer appropriate to use this estimate in management. Furthermore, the recent discovery of genetically different sub-populations of Hector's dolphins (Pichler et al. 1998) highlights the need for updated, fine-grained information on the distribution and abundance of Hector's dolphins.

The survey had two aims:

- To develop methodology suitable for surveying coastal cetacean species such as Hector's dolphin.
- To provide a baseline estimate of Hector's dolphin abundance for the Motunau–Timaru area against which future surveys can be compared.

Elsewhere in the world, line-transect surveys for cetaceans are generally carried out from large (>50 m) vessels, such as those run by the National Oceanic and Atmospheric Administration (NOAA) in the USA. These vessels are very expensive to run (>$US10,000/day). Even if this was affordable, large vessels cannot safely work in shallow, confined waters. These two constraints necessitate the use of much smaller vessels for surveying highly coastal dolphins such as Hector's dolphin. We adapted line transect survey methods (e.g. Barlow 1988) for use on a privately owned 15 m catamaran (*RV Catalyst*), which 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 c.15 litres of diesel/h), and a safe working depth of 2 m.

The survey was the first boat-based line-transect survey conducted in New Zealand waters.

2. Methods

2.1 SURVEY DESIGN

Buckland et al. (1993) recommend placing transects across known density gradients, in order to gain a clearer picture of density and minimise variance in encounter rate. Since short-distance alongshore movements are well known for Hector's dolphins (Slooten & Dawson 1994), and the dolphins' density declines sharply with distance offshore (Dawson & Slooten 1988), transects were placed at 45º to the coast.

The survey was designed to estimate dolphin abundance in areas of intrinsic interest and areas of known differences in dolphin density. These areas (strata) were:

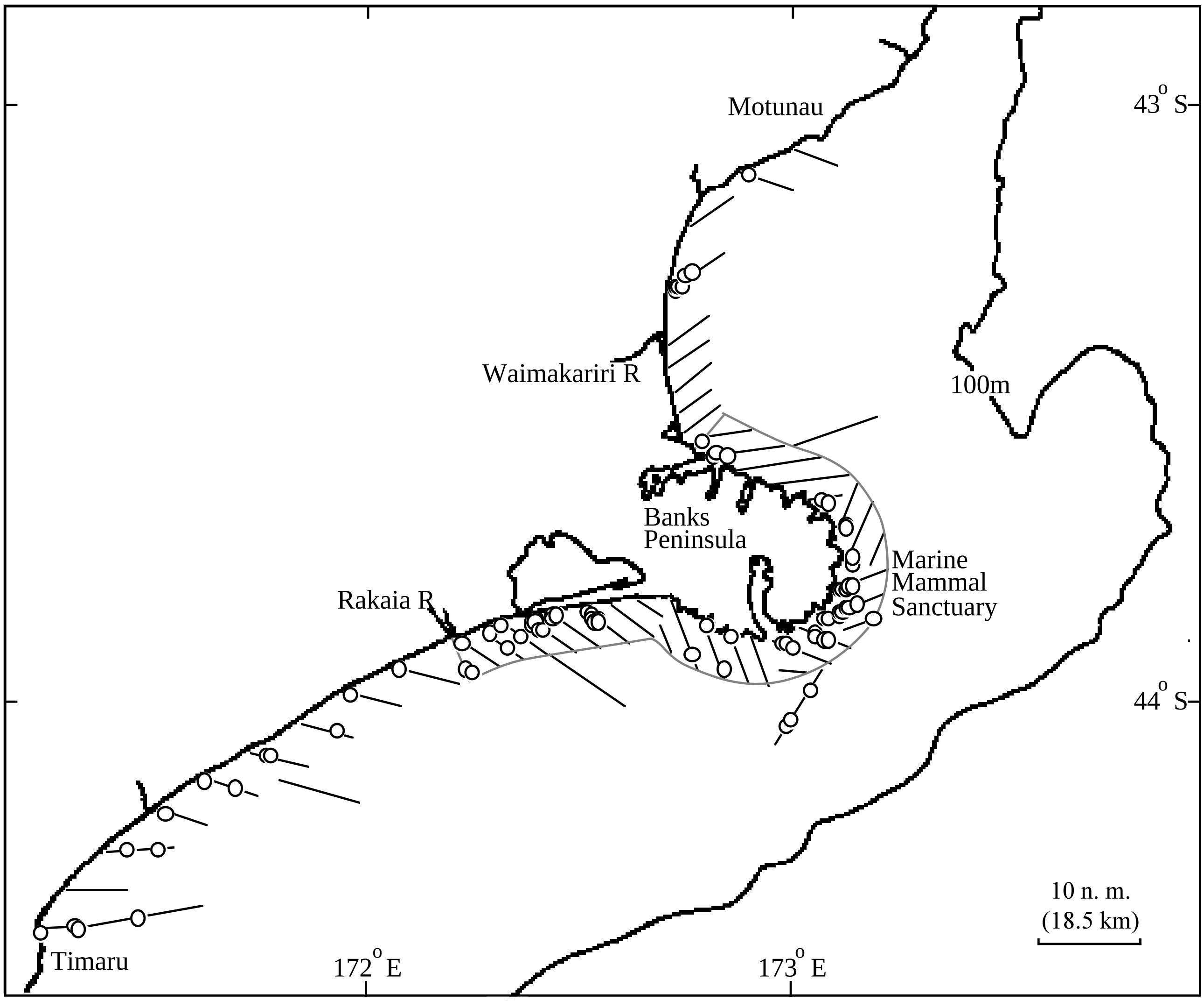

Figure 1. Survey strata, open coast transects (lines), and sightings (circles). Details of strata:
Akaroa Harbour (1 n. m. line spacing, 4 replicates)
Other harbours and bays >1 n. m. long (1 n. m. line spacing, 3 replicates)
Waimakariri River–Rakaia River (2 n. m. line spacing)
Waimakariri River–Motunau (4 n. m. line spacing)
Rakaia River–Timaru (4 n. m. line spacing)
4–10 n. m. offshore (c. 20 n. m. line spacing)

a. Akaroa Harbour.

b. Other large (>1 n. m. long) harbours/bays (Lyttelton Harbour, Port Levy, Pigeon Bay, Little Akaloa Bay, Okains Bay, Le Bons Bay, Otanerito Bay, Flea Bay, Gough's Bay, Peraki Bay, Te Oka Bay).

c. Banks Peninsula Marine Mammal Sanctuary (Sumner to Rakaia River, to 4 n. m. offshore).

d. Inshore zone (within 4 n. m. of shore), to the north and south of the sanctuary. This area typically has much lower dolphin densities than the sanctuary area.

e. Offshore zone from Motunau to Timaru, 4–10 n. m. from shore. This stratum was not a high priority for survey effort because all offshore transects to date have shown this area to be of low density. Preliminary calculations showed that >1100 n. m. of trackline would be needed to estimate effective strip width in this zone. We are not aware of any reliable sightings of Hector's dolphins beyond 10 n. m. offshore.

To ensure that coverage within strata (c) and (d) was as equal as possible we divided the coastline into small blocks, plotting transect lines at 45° to the baseline of each block. The strata surveyed, and the survey lines outside the Harbours and Bays are shown in Fig. 1. Within harbours we placed lines at 45° to an imaginary line down the centre of the harbour (see Fig. 2 for example of survey lines within Akaroa Harbour).

Transect lines were spaced 1 n. m. apart within harbours and bays, 2 n. m. apart within the sanctuary area and 4 n. m. apart in the areas to the north and south of the sanctuary (Fig. 1). In each case the start point was randomised. We laid out one offshore line (stratum e) off each coastal block.

Line transect theory uses the distances at which sightings were made from the vessel trackline (perpendicular distance) to calculate the distance over which it can be assumed that all dolphins are seen. This distance is called Effective Strip Width (ESW). Our goal was to estimate ESW separately for the harbour strata (strata a and b above) and for strata outside harbours (b–d). Preliminary calculations showed that unrealistic effort levels would be needed to estimate ESW separately for each stratum. Additionally, since sighting conditions were similar in all non-harbour strata, the advantage of doing so is not obvious. To reach a target of 60–80 detections for robust ESW estimation (Buckland et al. 1993), we conducted replicate surveys (with a new set of lines each time) of the harbours and bays within the harbours strata.

2.2 FIELD METHODS

To minimise the chance of missing groups, the observer platform must be stable, and sightings made only in good weather conditions. 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.

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. Sightings made by the centre observer were not used in analysis because his/her sighting effort is unavoidably uneven (cannot make sightings while recording another sighting). The left and right observers used seven-power binoculars to minimise the effect of reactive movement by the dolphins before detection. Observers 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 were used to measure the downward angle from the land, or horizon, to the sighting. 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). Sighting angles were recorded using angle boards (see Buckland et al. 1993). We measured the accuracy of the radar by comparison with transit fixes and laser rangefinder measurements, and applied this correction to all radar measurements.

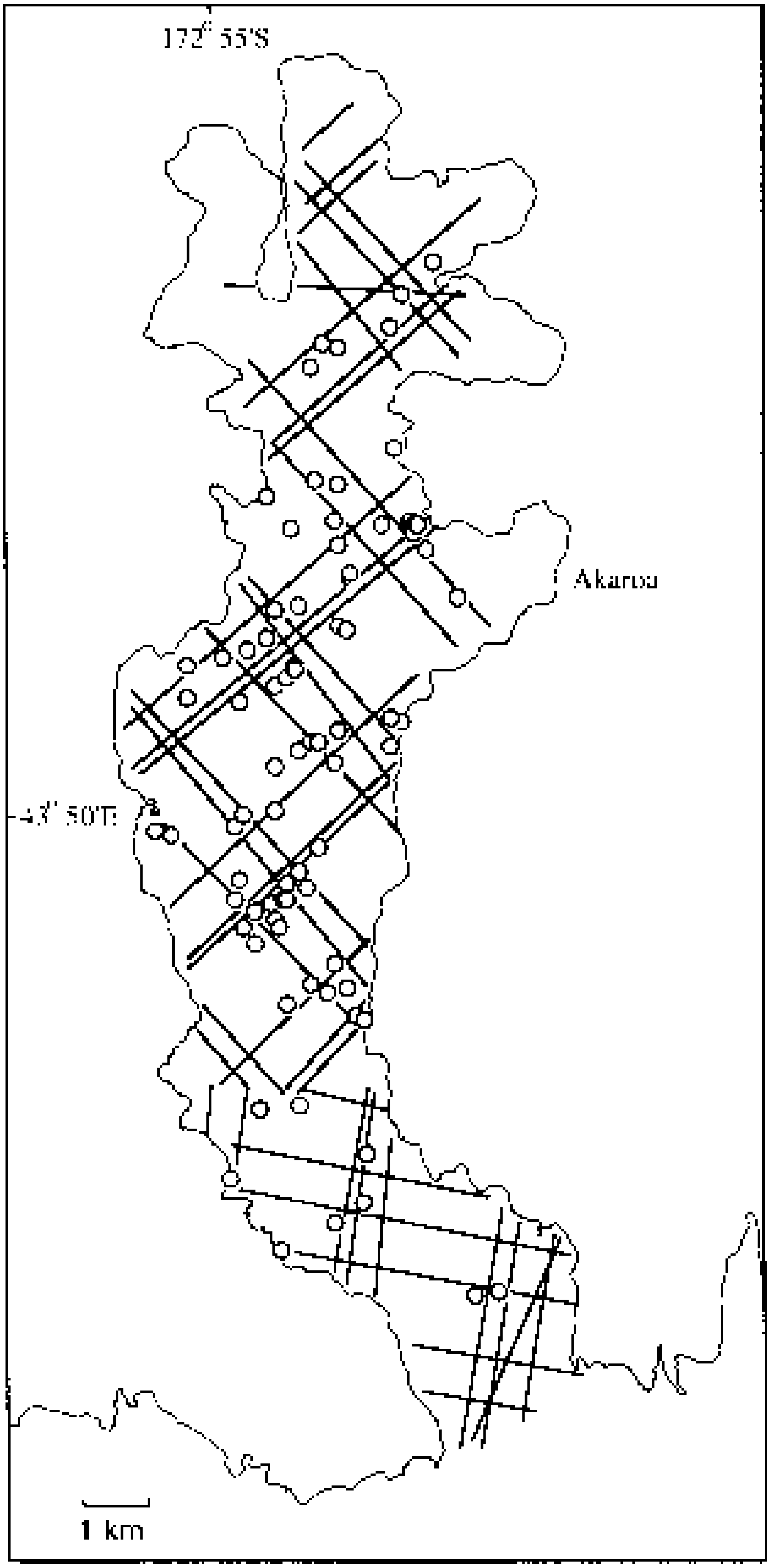

Figure 2. Transects (lines) and sightings (circles) in Akaroa Harbour (4 replicate surveys).

Navigation was facilitated by the use of a 12 channel GPS Chartplotter (Cetrek 343). 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 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.

Several days were spent training observers (data gathered in this period were not used in analysis). An observer manual precisely specified observation methods (unpublished report, available from authors). To improve consistency, observers regularly re-read the manual throughout the survey. While the survey was underway, exploratory data analyses were undertaken to assess data quality. These analyses showed that in early stages of the survey, observers were rounding angles of sightings close to the trackline to zero. Sighting procedures were modified to minimise this problem, and survey lines with suspect sightings (e.g. 'spikes' in histogram of sighting angles due to inaccurate measurement) were repeated.

2.3 DATA ANALYSIS: ABUNDANCE ESTIMATION

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

$$N = \frac{A\ n\ s}{2\ L\ ESW\ \ g(0)} \tag{1}$$

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, and
$g(0)$ = probability of seeing a group directly on the transect line.

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.

Plots of perpendicular distance against group size for 'harbours and bays', and 'outside harbours' strata revealed no relationship (R^2 = 0.0456 and 0.0006 respectively). Expected group size was therefore estimated as a simple mean group size.

Using the program DISTANCE (Laake et al. 1993) a hazard key function with cosine adjustments (harbours and bays stratum) and a uniform key function with cosine adjustments (all other strata) were fitted to perpendicular distance data to estimate effective strip width *ESW*. *ESW* is defined as $1/f(0)$, i.e. the inverse of the probability density function (fit to the distribution of perpendicular sighting distances) evaluated at zero distance. 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 600 m and binned manually for *f(0)* estimation. Sightings for which range (radial distance) was estimated by eye were not used for *f(0)* estimation, because we found these distance estimates to be highly inaccurate, but were used in abundance calculations. Observers consistently under-estimated radial distances by eye, and using these sightings resulted in spiked data. This made fitting a model to the perpendicular sightings difficult, and artificially narrowed *ESW*. The probability of seeing a group directly on the trackline (*g(0)*) is assumed to be 1.0.

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

$$CV(N) = \sqrt{CV^2(n) + CV^2(S) + CV^2(ESW)} \qquad (2)$$

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

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

where:

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

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. Model selection for data collected outside harbours was constrained to avoid hazard functions, which can give poor fits to spiked or slightly spiked data (Fig. 3; J. Laake, pers. comm.). Upper and lower 95% confidence intervals for *N* were calculated using

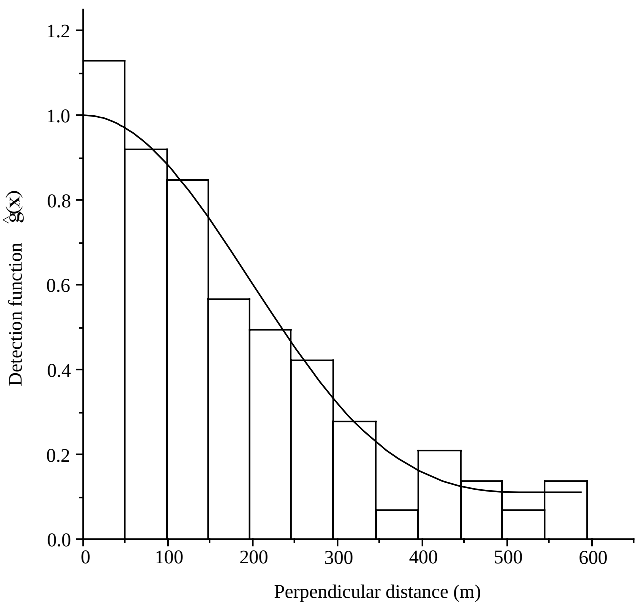

Figure 3. Frequency distribution of sightings within binned perpendicular distances, and the fitted detection function for strata outside harbours and bays.

the Satterthwaite degrees of freedom procedure outlined in Buckland et al. (1993). This procedure assumes a log-normal distribution, using:

$N_L = N/C$, and

$$N_U = N\,C \tag{5}$$

where:

$$C = \exp\left\{t_{df}\,(0.025)\ \sqrt{\log_e(1+[CV\,(N)]^2)}\right\} \tag{6}$$

(See Buckland et al. 1993 for a full explanation of this procedure.)

The Harbours and Bays stratum was post-stratified and Akaroa was treated as a separate stratum for abundance estimation. An abundance estimate was not calculated for the offshore zone due to the small number of sightings.

3. Results

3.1 SURVEY EFFORT AND SIGHTINGS

Generally good weather ensured we were able to do at least some surveying on 31 days of 49 days in the field. We covered over 3000 n. m. in the process of surveying 405 n. m. (751 km) (Table 1). As expected, the highest sighting rates occurred in Akaroa Harbour (Fig. 2) and within the Banks Peninsula Marine Mammal Sanctuary (Fig. 1). High sighting rates also occurred outside the Sanctuary, both to the North and South, particularly on a few transects (Fig. 1).

TABLE 1. SURVEY EFFORT AND SIGHTINGS.

STRATUM		SURVEY EFFORT (km)	NUMBER OF SIGHTINGS	SIGHTINGS/km	AREA (km^2)
(a & b)	Harbours and Bays	223	89	0.399	116
(c)	Sanctuary minus (a & b)	265	66	0.249	1116
(d)	< 4 n. m. offshore, to the north and south of (c)	174	21	0.121	1321
(e)	Offshore (4–10 n. m.)	89	4	0.045	3288
Total		751	170		5841

3.2 ABUNDANCE

Seventy-one sightings are available for calculating ESW in the harbours strata (Table 1, strata a & b), and 75 outside harbours (strata c – e). Both comfortably exceed Buckland et al.'s (1993) recommendation of a minimum of 60 sightings for reliable calculation of ESW. Perpendicular distance data (Figs 3, 4) were tidy in comparison to those of other recent surveys (e.g. Vidal et al. 1997) with high goodness of fit probabilities (0.969 and 0.993 for 'outside harbours' and 'harbours and bays' respectively).

Results of abundance calculations are given in Table 2. The encounter rate (sightings/km) on the few offshore transects was nine, six, and three times lower than in Harbours and Bays (strata a & b), the Sanctuary (c), and strata d respectively. This confirms the expectation that sightings are uncommon offshore, and provides too limited a basis for calculating an abundance estimate for this zone.

Figure 4. Frequency distribution of sightings within binned perpendicular distances, and the fitted detection function for harbours and bays.

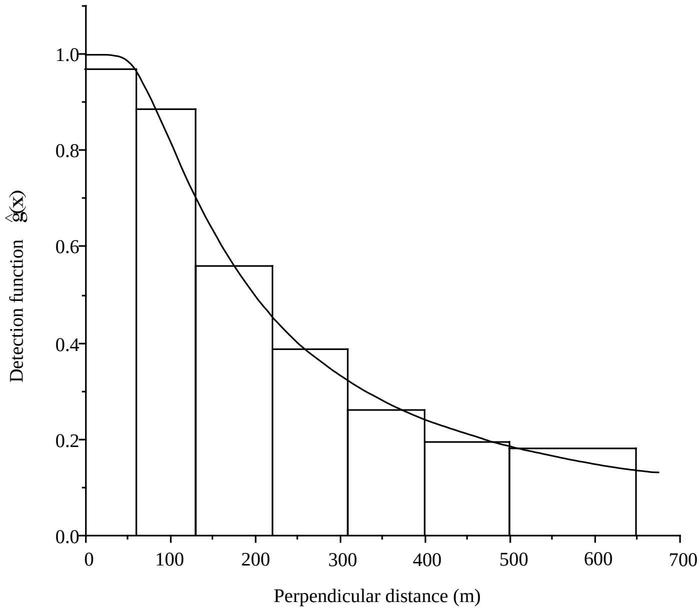

TABLE 2. ABUNDANCE ESTIMATES.

STRATUM	NUMBER OF GROUPS SEEN[1]	GROUP SIZES	EFFECTIVE HALF SEARCH WIDTH (m)	ESTIMATED ABUNDANCE (N)[2]	%CV (N)	LOWER 95% CONFIDENCE LIMIT	UPPER 95% CONFIDENCE LIMIT
Akaroa Harbour	56	3.16	275	124	28.1	69	222
Other harbours	8	3.00	275	29	64.7	2	189
Sanctuary (excluding harbours)	62	3.26	261	1631	16.5	1271	2091
Sanctuary (including harbours)	126			1784	22.4	1165	2728
Motunau-Timaru (excluding sanctuary and harbours)	19	2.16	261	597	32.4	270	1321
Study area (excluding offshore)	145			2381	20.3	1594	3557

Notes:

[1] This is the number used for the extrapolation from density to abundance, rather than for calculation of ESW (see text for explanation).

[2] Attraction of dolphins to the survey vessel means that these are likely to be over-estimates.

3.3 ANALYSIS BY BEAUFORT STATE

Information on sea state is usually collected during boat-based line transect surveys and sometimes used to post-stratify data (e.g. Barlow 1995). In our study this was not advantageous, for three reasons:

1. Because we avoided collecting data in conditions with whitecaps, only a few sightings were collected in Beaufort 3. Hence variance estimates for this Beaufort state are large.
2. Differences among Beaufort states for key parameters such as sighting rate, average group size and effective strip width were small and non-significant statistically (though statistical power is low due to 1. above).
3. Stratification by Beaufort state does not produce abundance estimates that match the zones of intrinsic management interest.

4. Discussion

4.1 ABUNDANCE ESTIMATES

The abundance estimates presented here seem high. It is likely, however, that these estimates are inflated (see below). If accepted at face value, a comparison with the only previous estimate available for the Motunau to Timaru area (832, Dawson & Slooten 1988), would imply either a population growth rate of 7.8%, or that the earlier estimate was biased low. Dolphins in general appear to have maximum population growth rates of 2–4% (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). A population growth rate of 7.8% therefore seems highly unlikely. That leaves the possibility that the previous estimate was biased low. Since considerable time was spent estimating how many groups were missed by observers in these surveys (Dawson & Slooten 1988), this also seems unlikely. The most plausible scenario is that the estimates presented here are inflated.

4.2 ATTRACTION OF DOLPHINS TO THE SURVEY VESSEL

During the survey we also recorded the orientation of dolphins when first seen, as one of four quadrants of 90°, representing 'towards', 'left', 'right', and 'away' from the point of view of the observer (Fig. 5). Dolphins heading left or right with respect to the observer should be more detectable, because they present a larger visual target (Palka & Hammond, in press). For this reason, if there is no reactive movement, more dolphins should be seen heading left or right than away or towards the observer. One would expect this effect to increase with increasing distance, as dolphins become harder to see. This general pattern is evident in Table 3 and Fig. 5.

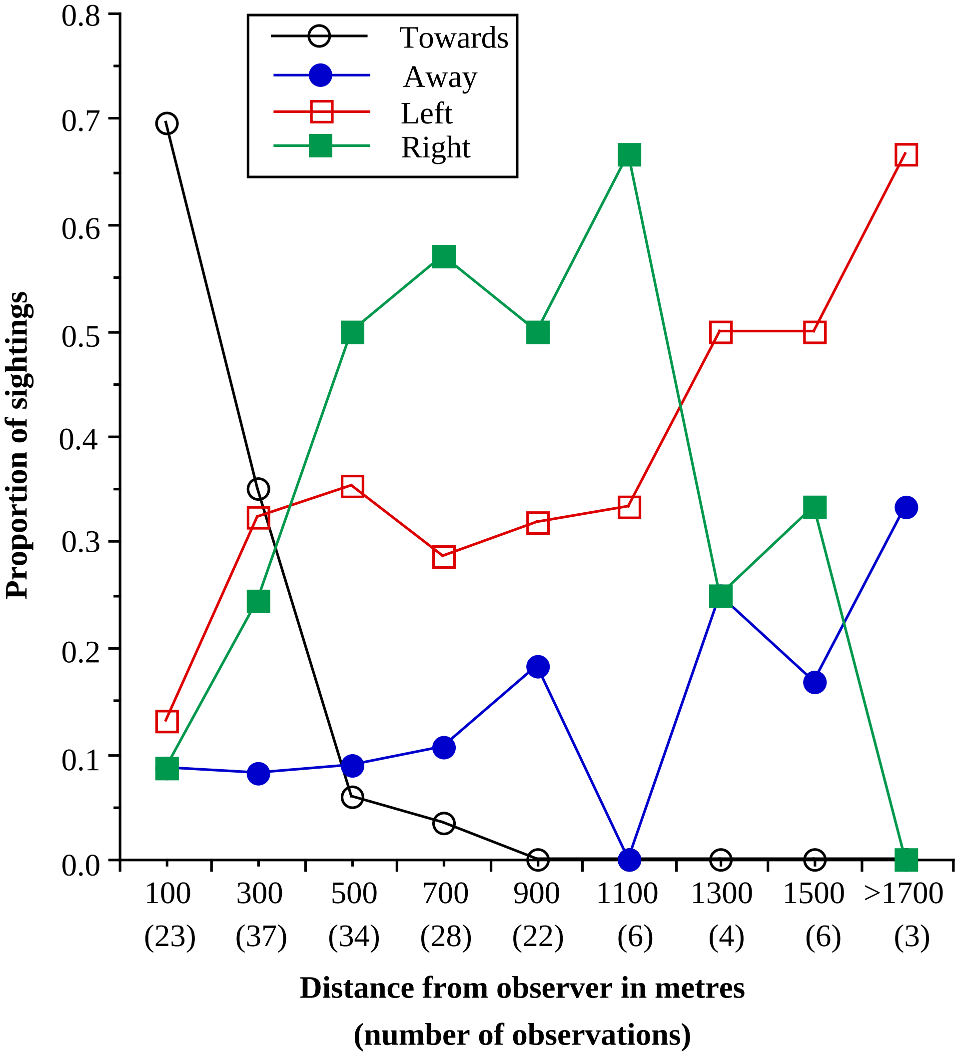

Figure 5. Orientation of dolphins relative to the vessel when first sighted by observers. Data are averaged over 200 m interval radial distance at the time of sighting.

TABLE 3. ORIENTATION OF DOLPHINS WITH RESPECT TO DISTANCE.

Radial distance of first sighting	Orientation Towards	Away	Left	Right
< 400 m	28	5	14	11
> 400 m	3	12	34	50

Under the null hypothsis of no responsive movement, the frequency of 'towards' v. 'away' orientations should be similar. Since both orientations present similar visual targets, the ratio between them should not differ with distance. To test these hypotheses we arbitarily chose a 400 m cutpoint of radial distance. The ratio of 'towards' v. 'away' orientations for sightings made within 400 m of the vessel spectacularly favoured 'towards' orientations by almost six to one (Log Likelihood ratio test of goodness of fit, $p = 0.00002$). The opposite trend, though not as strong, was significant for sightings made further than 400 m away from the vessel ($p = 0.02$). This demonstrates convincingly that dolphins are attracted to the survey vessel within 400 m.

Additionally, between 1985 and 1997 our research group has conducted 115 intensive zig-zag surveys of Akaroa Harbour from small boats (Dawson, Slooten & Bräger, unpubl. data). These surveys are designed differently to the current one and, if anything, might over-count numbers present since we sometimes saw distinctive animals more than once (for methods see Dawson 1991). The mean of the 38 surveys done in summer (Dec–Feb) was 43 (95% CI 34–52). The results from only three of those surveys fall within the 95% CI of the Akaroa line-transect estimate (69–222). This suggests that the line-transect estimate is an overestimate. This is a very important problem, especially when population estimates are used to judge the impact of fishery bycatches or set allowable catches. Responses by dolphins to survey vessels are a common problem for abundance surveys. Turnock et al. (1995) showed that unless corrected for attraction to the survey vessel, surveys of Dall's porpoises may provide abundance estimates up to six times too high.

The key question now is: what is the extent of the overestimation? Palka & Hammond's (in press) method for correcting for attraction is not applicable, because it requires two independent observation platforms on the same vessel. Moreover, it is not a complete solution because it relies on the assumption that far sightings made by observers on the top platform are uninfluenced by the vessel. For truly dependable results, it seems that this question need an empirical answer from specific field trials (e.g. simultaneous ship/helicopter surveys; Turnock et al. 1995). (Note that simultaneous helicopter/boat surveys were carried out in summer 1998/99 to quantify the effect of attraction of dolphins to the survey vessel. These surveys showed that uncorrected abundance estimates, such as those given here, should be halved. See DuFresne et al. (in press) for details of survey methodology and results.)

5. Further research

A common error in line-transect surveys is rounding of sighting angles (heaping). Heaping was evident in the first weeks of the Hector's dolphin survey and, rather than rely on analytical techniques to fix the problem (e.g. smearing), the decision was made to re-survey lines that showed this problem. Data will be re-sampled to quantify potential bias arising from this type of error, and to investigate the effectiveness of available analytical techniques. Data from the survey will also be used to explore the effects of different sampling regimes. For example, had previous knowledge of distribution been limited and different levels of stratification used, how would this have affected final results? Finally, alternative sampling designs will be explored to find an optimal compromise between cost and precision.

6. Acknowledgments

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