Abstract—Management of coastal species of small cetaceans is often impeded by a lack of robust estimates of their abundance. In the Austral summers of 1997–98, 1998–99, and 1999–2000 we conducted line-transect surveys of Hector's dolphin (*Cephalorhynchus hectori*) abundance off the north, east, and south coasts of the South Island of New Zealand. Survey methods were modified for the use of a 15-m sailing catamaran, which was equipped with a collapsible sighting platform giving observers an eye-height of 6 m. Eighty-six percent of 2061 km of survey effort was allocated to inshore waters (4 nautical miles [nmi] or 7.4 km from shore), and the remainder to offshore waters (4–10 nmi or 7.4–18.5 km from shore). Transects were placed at 45° to the shore and spaced apart by 1, 2, 4, or 8 nmi according to pre-existing data on dolphin density. Survey effort within strata was uniform. Detection functions for sheltered waters and open coasts were fitted separately for each survey. The effect of attraction of dolphins to the survey vessel and the fraction of dolphins missed on the trackline were assessed with simultaneous boat and helicopter surveys in January 1999. Hector's dolphin abundance in the coastal zone to 4 nmi offshore was calculated at 1880 individuals (CV=15.7%, log-normal 95% CI=1384–2554). These surveys are the first line-transect surveys for cetaceans in New Zealand's coastal waters.

Small-boat surveys for coastal dolphins: line-transect surveys for Hector's dolphins (*Cephalorhynchus hectori*)

Stephen Dawson[1]

Elisabeth Slooten[2]

Sam DuFresne[1]

Paul Wade[3]

Deanna Clement[2]

[1] Department of Marine Science
University of Otago
340 Castle Street
Dunedin, New Zealand
E-mail address: steve.dawson@stonebow.otago.ac.nz

[2] Zoology Department
University of Otago
340 Castle Street
Dunedin, New Zealand

[3] National Marine Mammal Laboratory
National Marine Fisheries Service
7600 Sand Point Way NE
Seattle, Washington 98115

Several international workshops on cetacean bycatch problems have stated that a key impediment to the conservation of coastal and riverine small cetaceans is the lack of quantitative data on abundance (e.g., IWC, 1994). An important reason for this lack of data is that line-transect surveys are often conducted from large (>50 m) vessels (e.g. Barlow, 1988) and hence are extremely expensive ($US 10,000/day). Such costs usually put high-quality surveys such as those conducted for harbor porpoise in the U.S. (e.g., Carretta et al., 2001) beyond the reach of less affluent nations. The need for abundance estimates is especially great for the coastal and riverine species found in Asia, Africa, Australasia, and South America (Table 1). Several of these species have apparently small populations and restricted distributions, and all suffer from being taken as bycatch in fishing gear, principally in gill nets (IWC, 1994). In addition, it is difficult or impossible for large vessels to work close to shore, in shallow waters, where some of these species are most common.

The work described in this contribution had two aims: 1) to adapt ship-based line-transect methods (e.g., Barlow, 1988) to a 15-m catamaran, and 2) to provide an updated estimate of the abundance of Hector's dolphin (*Cephalorhynchus hectori*). Hector's dolphin, a small delphinid found only in the inshore waters of New Zealand, is subject to bycatch in gill nets throughout its range (Dawson et al., 2001). At least in the Canterbury region, and off the North Island west coast, recent catch levels are clearly unsustainable (Dawson and Slooten, 1993; Martien et al., 1999; Slooten et al., 2000; Dawson et al., 2001). Studies of mt-DNA indicate that the very small North Island population is distinct and that there are at least three separate populations in South Island waters (Pichler et al., 1998; Pichler and Baker, 2000; see also Baker et al., 2002). At the time of the present study the only quantitative population estimate was from a strip-transect survey conducted in 1984–85 (Dawson and Slooten, 1988), in which the offshore distribution, as well as the

proportion of dolphins detected within the strip, was estimated. A current, more robust estimate is needed for management. This study describes line-transect boat surveys conducted to estimate Hector's dolphin abundance on the north, east, and south coasts of the South Island of New Zealand.

Figure 1
Photograph of the observer platform on the catamaran *Catalyst*.

Materials and methods

Vessel choice and field methods

Displacement catamarans are inherently suitable for inshore surveys because of their resistance to rolling and their ability to sustain reasonably high cruising speeds with modest power. We based our surveys from a 15.3-m sailing catamaran (RV *Catalyst*), which is powered by two 50-hp diesel engines, and cruises at 9–10 knots while using <10 liters of fuel per hour. We fitted a collapsible aluminum sighting platform (~6 m eye height; Fig. 1) to increase the resolution with which observers could measure the downward angles to sightings (see Lerczak and Hobbs, 1998, for details) and to allow the observers to see animals farther away. The surveys were conducted with a crew of six (five observers, one skipper).

Three people stood on the platform at any given time; one scanned the surface waters to the right of the platform, and the other scanned to the left, and a third person (the recorder) recorded sightings dictated by the observers. Sightings made by the recorder were not used in our analyses because his or her sighting effort was unavoidably uneven (the recorder could not make sightings while recording another sighting). The recorder did not point out sightings to observers. Observers and data recorder rotated

Table 1		
Examples of coastal and riverine species of special conservation concern.		
Common name	Scientific name	Habitat
Vaquita	*Phocoena sinus*	Northern Gulf of California
Chilean dolphin	*Cephalorhynchus eutropia*	Inshore coastal Chile
Hector's dolphin	*Cephalorhynchus hectori*	Inshore coastal New Zealand
Commerson's dolphin	*Cephalorhynchus commersoni*	Inshore coastal Chile, Argentina, Falkland Is, Kerguelen Is.
Heaviside's dolphin	*Cephalorhynchus heavisidii*	Inshore coastal South Africa and Namibia
Peale's dolphin	*Lagenorhynchus australis*	Coastal Chile, Argentina, Falkland Is.
Finless porpoise	*Neophocoena phocaenoides*	Coastal and riverine Asia and Indonesia
Indo-Pacific humpbacked dolphins	*Sousa chinensis*	Inshore tropical and estuarine habitats in western Pacific and Indo Pacific
Burmeister's porpoise	*Phocoena spinipinnis*	Coastal Chile, Argentina, Uruguay, Brazil
Franciscana	*Pontoporia blainvillei*	Coastal Brazil and Argentina
Indus river dolphin	*Platanista minor*	Indus River
Ganges river dolphin	*Platanista gangetica*	Ganges, Bramaputra, Karnphuli, Meghna rivers
Boto	*Inia geoffrensis*	Amazon River
Tucuxi	*Sotalia fluviatilus*	Coastal and estuarine Atlantic Central and South America

every 30 minutes to avoid fatigue. Although Hector's dolphins are easily identified from other species, and group size is typically small (usually 2–8; Dawson and Slooten, 1988), in order to maintain even sighting effort on both sides of the trackline, observers did not confer during a sighting. Sighting information was entered into a custom-written program on a Hewlett-Packard 200LX palmtop computer on the sighting platform. Data recorded included horizontal sighting angle, downward angle to sighting (in reticles), species, group size, orientation of the animals when first sighted, depth, Beaufort sea state, swell height, glare, GPS fix, date, and time. The program also recorded survey effort by storing a GPS fix every 60 seconds. Weather conditions were recorded at the start of field effort, and whenever they changed.

Observers used reticle- and compass-equipped Fujinon 7×50 (WPC-XL) binoculars to make sightings and to measure the downward angle from the land, or horizon, to the sighting. If the former, the corresponding distance to land was measured with RADAR (Furuno 1720 model), or, if within a few hundred meters of shore, with a Bushnell lightspeed laser rangefinder (tested accuracy ±1 m from 12 to 800 m). We calibrated the accuracy of the RADAR by comparison with transit fixes and laser rangefinder measurements. Sighting angles were recorded by using angle boards (see Buckland et al., 1993) in the first season, and thereafter with the compasses in the binoculars. There were no ferrous metals or significant electrical fields within 6 m of the sighting platform.

Navigation was facilitated by the use of a Cetrek 343 GPS chartplotter with digitized C-MAP charts onto which transect waypoints were plotted. Depths were measured with a JRC JFV-850 echosounder (at 200 kHz).

At the start of each survey, several days were spent training observers at Banks Peninsula, where sighting rates are high. Training continued until we gained about 100 sightings (data gathered in this period were not used in the analyses). An observer manual (available from authors) specified scanning behavior and recording methods. To ensure a wide shoulder on the histograms of perpendicular sighting distances, observers were instructed to concentrate their effort within 45° of the trackline and to spend less time searching out to 90°. Observers spent about 85% of the time scanning with binoculars. Regular scans with the naked eye minimized fatigue and reduced the chance of missing groups close to the boat. To promote consistency, observers were asked to re-read the manual at least once a week throughout the survey.

While the survey was underway, exploratory data analyses were undertaken to assess data quality. These analyses showed that in the early stages of the first survey, observers were rounding angles of sightings close to the trackline to zero. The use of the angle boards was modified to minimize this problem, and they were not used in subsequent surveys. The data from these early lines were discarded and the survey lines repeated.

Survey effort was restricted to sea conditions of Beaufort 3 or less and swell heights of ≤2 meters. Transect lines were run down-swell and down-sun to minimize pitching and effects of glare. Deviations of up to 10° from the intended course were made if needed to further reduce pitching or glare. The inshore end of each line was surveyed to just outside the surf zone on open coasts, or until a 2 m depth was reached, or to within 50 m of rocky shores. All surveys were conducted in passing mode to minimize the extent of vessel attraction.

Line-transect data were collected in three surveys in three consecutive summer seasons, each focussing on a particular coastal area (Fig 2; Motunau to Timaru, 5 January–21 February 1998; Timaru to Long Point, 9 December 1998–16 February 1999; Farewell Spit to Motunau, 17 December 1999–28 January 2000).

Survey design

In order to obtain a clear picture of density and to minimize variance in encounter rate, Buckland et al. (1993) recommend placing transects across known density gradients. Because short-distance, alongshore movements are well-known for Hector's dolphins (Slooten and Dawson, 1994; Bräger et al., 2002) and the dolphins' density declines sharply with distance offshore (Dawson and Slooten, 1988), transects were placed at 45° to the coast. On curved coastlines (within strata) we divided the coastline into blocks, drew an imaginary baseline along the coast, and placed lines at 45° to that baseline. The starting point of the first line along the baseline was decided randomly; thereafter lines were spaced at regular intervals according to the sampling intensity required in that stratum (Fig. 2). Within harbors we placed lines at 45° to an imaginary line down the center of the harbor (Fig. 3). The aim of this scheme was to ensure that, within a stratum, any one point had the same chance of being sampled as any other.

Survey effort was stratified according to existing data on distribution, obvious habitat differences, and areas of intrinsic management interest. In summer, very few Hector's dolphins are seen beyond four nmi from shore (Dawson and Slooten, 1988); therefore most sampling effort was placed in this inshore zone (i.e. 45° lines at 2-, 4-, or 8-nmi spacings, approximately proportional to density as determined from previous surveys). Within harbors, transect spacings were either one or two nautical miles. In the offshore zone (from 4 to 10 nmi) we expected very low densities, and therefore used sparse transect spacing (~30 nmi apart). It was not our intention to estimate density in this offshore zone. A subsequent aerial survey was found to be better suited for this purpose (Rayment et al.[1]).

Our goal was to estimate effective half strip width (ESW) separately for strata with different exposure to wind and swell. Hence, in each survey we aimed to gain sufficient sightings to estimate ESW separately for harbors or protected waters, and open coasts. To reach

[1] Rayment, W., E. Slooten, and S. M. Dawson. 2003. Unpubl. data. Department of Marine Science, Univ. Otago, P.O. Box 56, Dunedin, New Zealand.
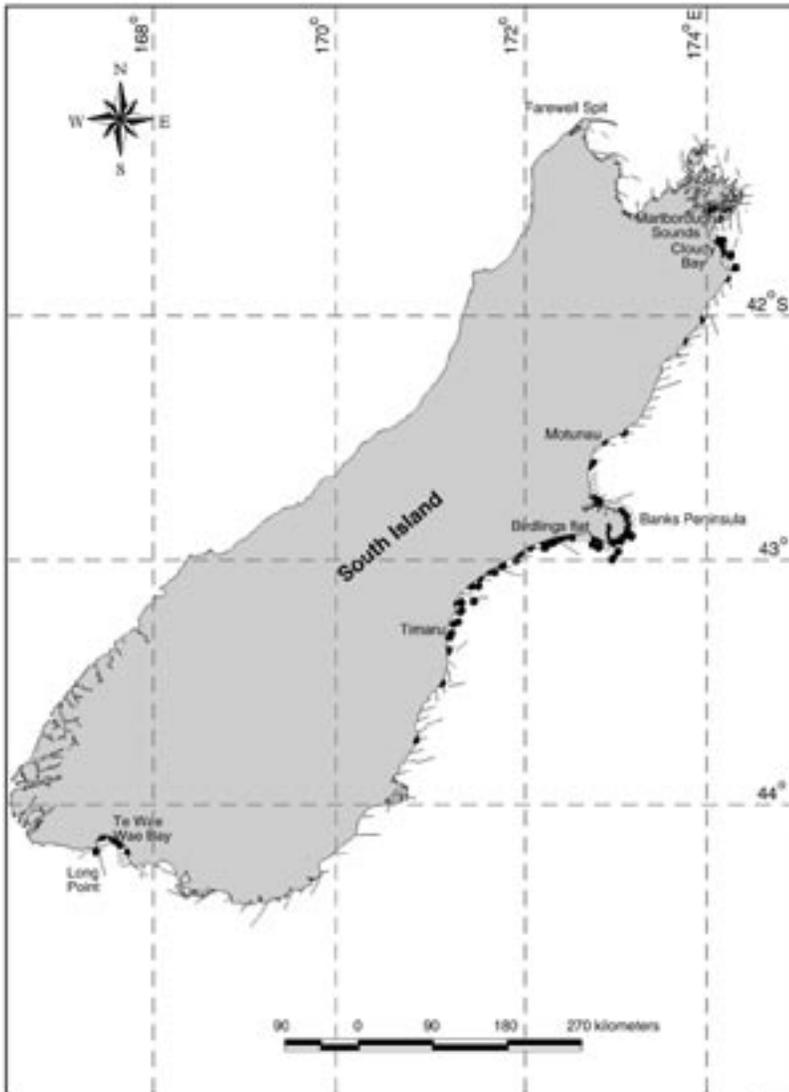
Figure 2

Map of New Zealand's South Island, showing transect lines and sightings of Hector's dophins (dots) 1997–2000.
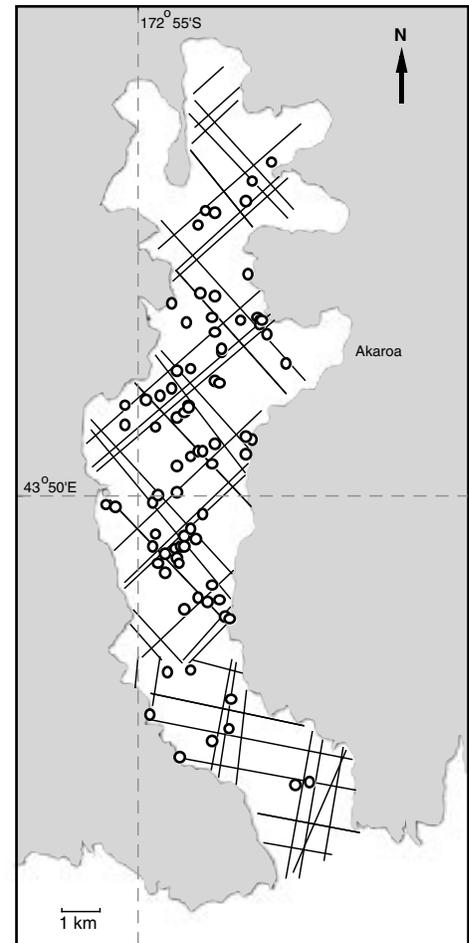

Figure 3

Example of transect layout in harbors (1997–98 Akaroa Harbor transect lines and sightings, showing three replicates).

Buckland et al.'s (1993) target of 60–80 detections for robust ESW estimation, in the 1997–98 survey we conducted replicate surveys (with a new set of lines each time) in the harbors and bays stratum (e.g., Fig. 3). Low sighting rates in the area surveyed in 1999–2000 would have required unrealistic effort levels to reach this target; therefore we gained extra sightings from areas with the same exposure but higher sighting rates (e.g., data used to calculate ESW for the Marlborough Sounds were supplemented by data gathered in Akaroa Harbour by the same observers, in the same summer). Hence different sample sizes were available to estimate density and ESW (Table 2). Because observers changed between surveys, we did not pool sightings across years for estimating ESW. Strata areas were measured from nautical charts with a digital planimeter.

Data analysis

Within each stratum, Hector's dolphin abundance (N_S) was estimated as (Buckland et al., 1993):

$$\hat{N}_s = \frac{AnS}{2LESW},\qquad(1)$$

where A = size of the study area;
$\quad n$ = number of groups seen;
$\quad S$ = expected group size;
$\quad L$ = length of transect line surveyed, and
ESW = the effective half strip width.

Because there was no significant relationship between group size and detection distance, expected group size was estimated as a simple mean group size.

Table 2

Survey effort by stratum. Number of sightings is the total number made before truncation and quality auditing (see "Vessel choice and field methods").

Survey zone	Stratum	Survey effort (km)	No. of sightings	Sightings per km
Motunau to Timaru (1997–98)	Banks Peninsula harbors and bays	223	89	0.399
	Banks Peninsula Marine Mammal Sanctuary (BPMMS) (excluding open coasts)	265	66	0.249
	<4 nmi offshore, to the north and south of BPMMS	174	21	0.121
	Offshore (4–10 nmi)	89	4	0.045
Timaru to Long Point (1998–99)	Timaru–Long Point (excluding Te Waewae Bay)	336	13	0.04
	Te Waewae Bay	101	14	0.14
	Offshore (4–10 nmi)	106	0	0
Motunau to Farewell Spit (1999–2000)	Farewell Spit–Stephens Island	120	0	0
	Marlborough Sounds (including Queen Charlotte Sound)	205	3	0.015
	Cape Koamaru–Port Underwood	68	0	0
	Cloudy Bay and Clifford Bay	89	13	0.146
	Cape Campbell–Motunau	192	5	0.026
	Offshore (4–10 nmi)	93	2	0.022

Using the program Distance 3.5 (Research Unit for Wildlife Population Assessment, University of St. Andrews, UK), we fitted detection functions to perpendicular distance data to estimate ESW (note that this value is derived directly from $f(0)$). Akaike's information criterion (AIC) was used to select among models fitted to the data. Models and adjustments were the following: hazard/cosine, hazard/polynomial, half-normal/hermite, half-normal/cosine, uniform/cosine (Buckland et al., 1993). Following Buckland et al. (1993), perpendicular sighting distances were truncated to eliminate the farthest 5% of sightings 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 (Buckland et al., 1993):

$$CV(\hat{N}_S) = \sqrt{CV^2(n) + CV^2(S) + CV^2(ESW)}. \tag{2}$$

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

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

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

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

CV(S) was estimated from the standard error of the mean group size. *CV(ESW)* was estimated with the bootstrapping option in Distance 3.5 software. This process incorporates uncertainty in model fitting and model selection (Buckland et al., 1993).
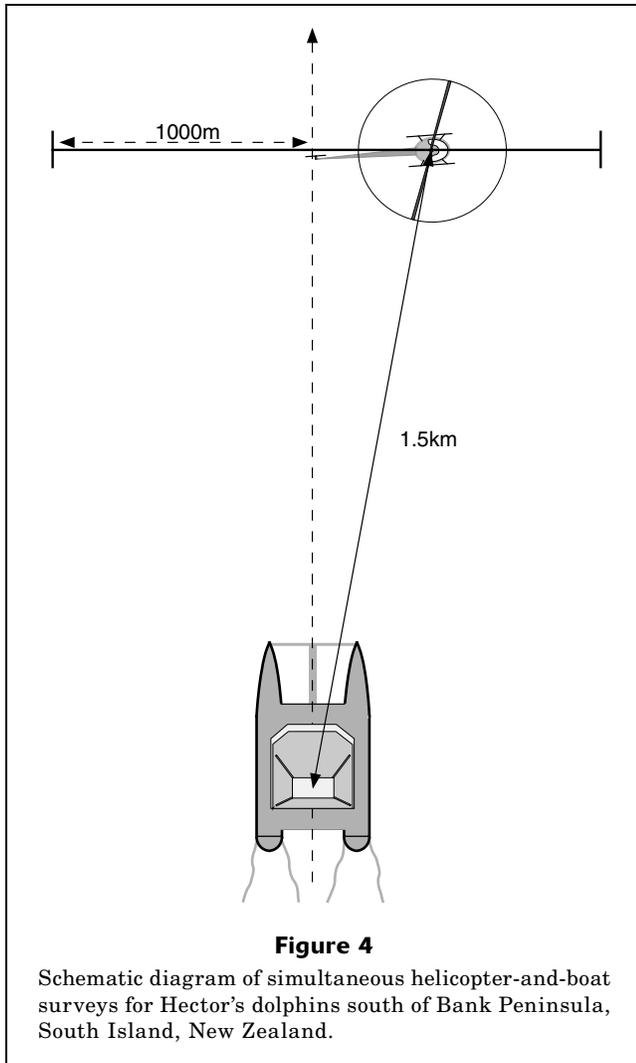
Measuring the effect of attraction

Conventional line-transect estimates can be biased as a result of responsive movement of the target species and animals on or near the trackline being missed by observers (Buckland et al., 1993). Buckland and Turnock (1992) presented a method using co-ordinated boat and helicopter surveys to quantify and adjust for the combined effects of responsive movements of dolphins to the boat and to eliminate the bias from observers failing to see animals on or near the trackline. Their approach is better suited to the restricted space available on small boats than to a dual-platform approach (Palka and Hammond, 2001). Additionally, sightings can be made much farther ahead (reducing the possibility that the animals have already responded), and the two sighting teams are totally isolated from each other. For these reasons we adapted Buckland and Turnock's (1992) approach in our trials of 1998–99.

Simultaneous boat-and-helicopter surveys 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.

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, traveling out to 1000 m on either side of the vessel's trackline at a height of 500 ft (152 m) (Fig. 4). To aid the process of tracking sightings from the air, sighting positions were marked with Rhodamine dye bombs.[2] The position of the helicopter in relation

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[2] Dye bombs consisted of a tablespoon of Rhodamine dye in a paper cup $2/3$ filled with sand. An additional (empty) paper cup was taped upside down on top of the first cup with paper-based masking tape. On impact the two cups broke apart, releasing the sand+dye mix into the water.

Figure 4

Schematic diagram of simultaneous helicopter-and-boat surveys for Hector's dolphins south of Bank Peninsula, South Island, New Zealand.

to the boat was determined with the boat's RADAR. The absolute position of the boat was determined to an accuracy of 2–5 m by differential GPS (Trimble GeoExplorer; postprocessed). Distances to land were obtained at the time of sighting with RADAR or during analysis by using GIS coastline data and the computer program "SDR Map" (Trimble Navigation, Christchurch, New Zealand).

Boat observers followed our standard sighting procedures (see above). On most occasions the helicopter was outside the field of view of the observers' binoculars because the observers were scanning the water surface, and the helicopter was well above what the observers could see through the binoculars. When it was within their view, observers made a conscious effort to remain unbiased by the movements of the helicopter. On making a sighting, the helicopter observer informed an independent observer located in the cabin (observers on the platform could not hear communications from the helicopter observer and vice versa). The helicopter then hovered briefly above the sighting while a range

and bearing in relation to the boat was taken by RADAR. The helicopter then ceased hovering but tracked the group of dolphins either until the boat observers had sighted the group, or the group had passed abeam of the boat. A second range and bearing were then taken. Sightings lost by the helicopter observer during tracking were discarded in our analyses. The independent observer, in liaison with the helicopter observer and boat observers, determined whether the sighting was a duplicate (i.e., made by both helicopter and boat observers) by using information on location and group size. These decisions were checked again in analysis by inspection of plotted locations of sightings made from either platform or both platforms.

Following the approach of Buckland and Turnock (1992), let

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

$$f_S(y) = g_S(y) / \mu, \text{ with } \mu = \int_0 g(y)dy$$

(area under helicopter detection function),

w = truncation distance for perpendicular distances y;
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 fitted to helicopter detection distances;
$f_{hs}(y)$ = probability density function fitted to duplicate detection distances as recorded from the helicopter;
$f(x)$ = probability density function fitted to 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

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

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

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

A correction factor for abundance estimates of Hector's dolphin groups can be estimated by

$$\hat{c} = \hat{D}_U / \hat{D}_S. \qquad (9)$$

Using Distance 3.5, we fitted a half-normal model with cosine adjustments 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 by using AIC. Potential model choices were the following: hazard/cosine, hazard/polynomial, half-normal/cosine, half-normal/hermite and uniform/cosine (Buckland et al., 1993). Truncation distance was 640 m for boat sightings, and 1000 m for helicopter and duplicate sightings. To ensure that only high-quality data were used to estimate effective half search widths, sightings for which range (radial distance) was estimated by eye and those made during Beaufort sea state >2 were removed before $f(0)$ estimation.

The error for the correction factor ($\hat{c}$) was estimated by bootstrapping on 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 $\hat{c}$.

Ideally, the correction factor would be estimated separately for each survey from separate sets of boat-and-helicopter trials conducted in areas of representative density. Financial and logistical constraints prevented this; therefore the correction factor estimated in 1998–99 was applied to each of the line-transect surveys reported in the present study. We note that this is not uncommon (e.g., Carretta et al., 2001).

Unbiased abundance estimates were calculated by

$$\hat{N}_U = \hat{c}\hat{N}_S. \qquad (10)$$

The CVs of the corrected abundance estimates ($\hat{N}_U$) were calculated with the following equation (Turnock et al., 1995):

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

where $CV(\hat{c}) = \dfrac{SE(\hat{c})}{\hat{c}}. \qquad (12)$

Upper ($\hat{N}_{UC}$) and lower ($\hat{N}_{LC}$) 95% confidence intervals for $\hat{N}_U$ were calculated by using the Satterthwaite degrees of freedom procedure outlined in Buckland et al. (1993). This procedure assumes a log-normal distribution of N_C, using

$$\hat{N}_{LC} = \hat{N}_U / C, \text{ and} \qquad (13)$$
$$\hat{N}_{UC} = \hat{N}_U C,$$

where $C = \exp\left\{ t_{df}(0.025)\sqrt{\log_e\left(1 + \left[CV(\hat{N}_U)\right]^2\right)} \right\}. \qquad (14)$

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

Table 3

Summary of variables required for correction factor (boat-and-helicopter trials)

Parameter	Estimate
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
ESW of helicopter (km)	0.532
ESW for duplicates (km)	0.342
Apparent 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 (c)	0.5032
Standard error, SE(c)	0.0912

$$df = \frac{CV^4(\hat{N}_U)}{\dfrac{CV^4(\hat{c})}{B-1} + \dfrac{CV^4(\hat{N}_S)}{df_S}}, \qquad (15)$$

where B is the number of bootstrap samples, and df_S is the Satterthwaite degrees of freedom for the uncorrected abundance estimate, $\hat{N}_S$ (see Buckland et al., 1993).

The CV of combined abundance estimates ($\hat{N}_{Ui}$) was computed by

$$SE(total) = \sqrt{\left\{ SE^2(\hat{N}_{U1}) + SE^2(\hat{N}_{U2}) + \ldots + SE^2(\hat{N}_{Ui}) \right\}}, \qquad (16)$$

and

$$CV(total) = \frac{SE(total)}{\hat{N}_U(total)}. \qquad (17)$$

Results

The three line-transect surveys covered 2061 km of transect, and 231 sightings were used to estimate density (Table 2). Sighting rates were highest around Banks Peninsula (Table 3).

The simultaneous boat-and-helicopter surveys indicated that boat observers missed 11.4% of the dolphins on the trackline, but that strong responsive movement towards the boat resulted in apparent densities twice as high as they normally would be (Table 3). If the observers' attention was drawn to dolphin groups by the position of the helicopter, the results of these trials would be biased. This is unlikely, however, because several groups sighted by the helicopter observer subsequently passed within 200 m of the boat and were not seen by observers. We saw no evidence that the dolphins were affected by the helicopter.

Detection functions for boat-and-helicopter sightings (Fig. 5, C and D) are relatively smooth in comparison
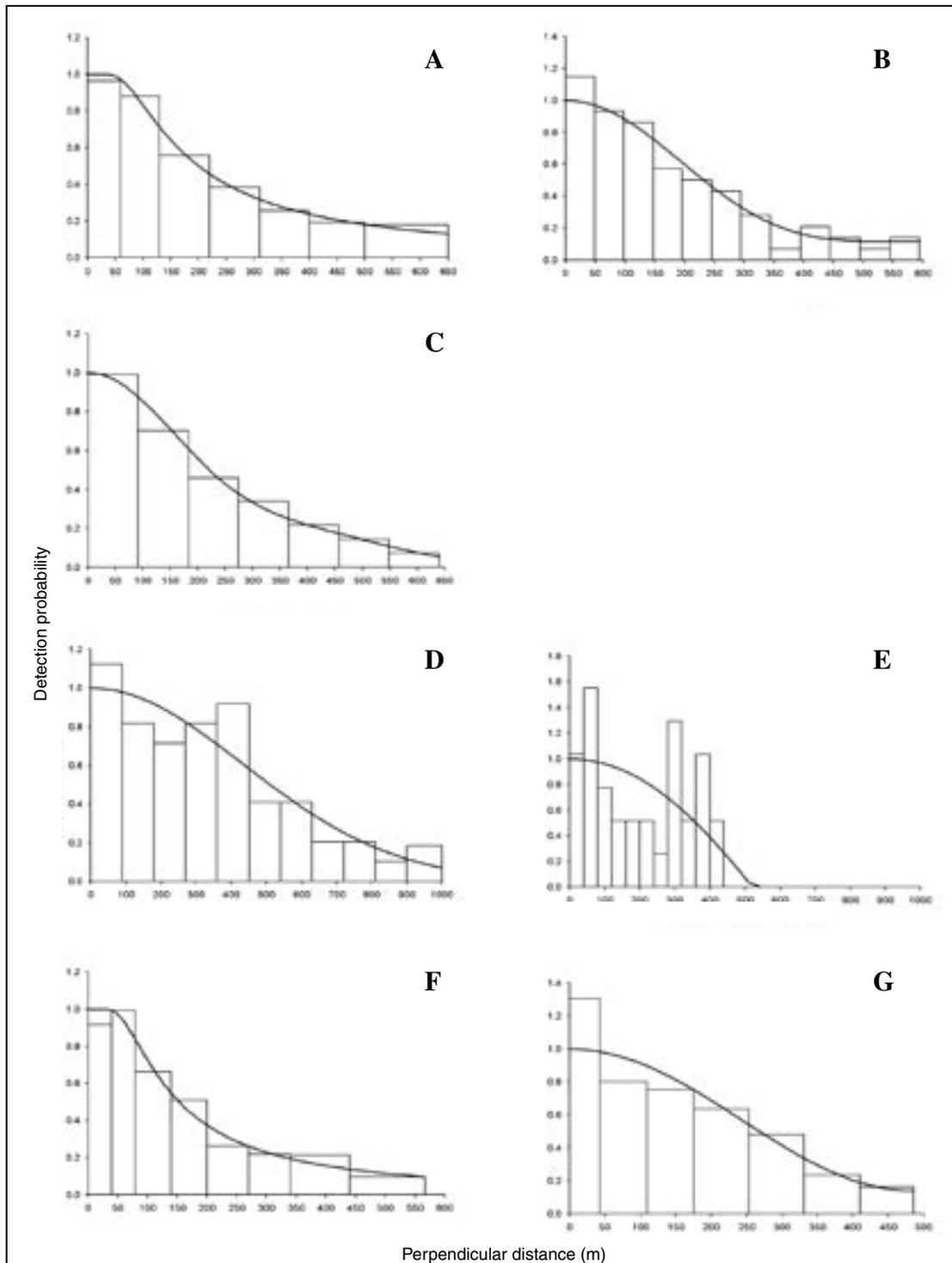
Figure 5

Histograms of perpendicular sighting distances, and their fitted detection functions as used to estimate effective strip width. n = number of sightings. The fitted model (hazard, cosine, uniform, or half normal) and any adjustments to it (cosine or none) are given in brackets. (**A**) 1997–98 harbors and bays (n=71; hazard/cosine); (**B**) 1997–98 open coasts (n=75; uniform/cosine); (**C**) 1998–99 open coasts (n=121; half-normal/cosine); (**D**) 1998–99 helicopter sightings (n=58; half-normal); (**E**) 1998–99 duplicate sightings (n=33; uniform/cosine); (**F**) 1999–2000 harbors and sounds (n=70; hazard/cosine); (**G**) 1999–2000 open coasts (n=89; uniform/cosine).

with those presented in Turnock et al. (1995). The detection function for the duplicate sightings (Fig. 5E) was more difficult to fit. Given the restricted sample size of duplicates (*n*=33), this result is not unexpected.

In the 1998–99 Timaru to Long Point and 1999–2000 Motunau to Farewell Spit surveys, robust estimation of ESW was facilitated by addition of extra sightings gained under similar sighting conditions at Banks Peninsula (Fig. 5, C, F, G). None of the three surveys showed significant evidence of larger groups being seen farther away. A broad pattern of abundance declining to the north and south of the Timaru–Banks Peninsula area is evident (Fig 2, Table 2). We made six sightings on 288 km of offshore lines (4–10 nmi offshore), confirming that densities in this zone are low.

Information on sea state is usually collected during boat line-transect surveys and sometimes used to poststratify data (e.g., Barlow, 1995). In our study this was not advantageous, for three reasons. 1) We avoided collecting data in conditions with whitecaps; therefore 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 showed overlapping confidence intervals (we concede that statistical power is low because of reason 1 stated above). Note that data were pooled in the same way as for ESW estimation. 3) Stratification by Beaufort state does not produce abundance estimates that match the zones of intrinsic management interest (e.g., Banks Peninsula Marine Mammal Sanctuary; Dawson and Slooten, 1993).

Discussion

The catamaran survey platform was a near-ideal vessel for close inshore surveys. The sighting platform (Fig. 1) was a relatively inexpensive modification (~US$2000) that could be dismantled in about 10 minutes to allow sailing. The vessel's minimal draught allowed coverage of very shallow areas, which are an important part of the distribution of Hector's dolphin and many other inshore cetaceans. Although catamarans are inherently resistant to rolling, pitching can be a problem when motoring into a head sea or swell. We minimized this pitching by arranging lines so they could be run down-swell. The 45° placement of lines facilitated this reduction in pitching because it provided two alternative sets of lines (at 90° to one another). Further, these could be run inshore or offshore, allowing a choice of four options.

A significant advantage of vessels with low running costs is that the cost of training is low. We could afford to spend 7–10 days training before each survey. Further, waiting for weather to improve is inexpensive; therefore one does not need to gather data in marginal sighting conditions.

Estimated abundances (Table 4) were not significantly different from those estimated in the 1984–85 strip transect survey. Recent mark-recapture estimates of dolphin abundance at Banks Peninsula in 1996, based on photo-ID data, differed from the line-transect estimate for this area by less than 6% (Gormley, 2002; Jolly-Seber model allowing different capture probabilities between first and subsequent captures).

Our surveys confirmed previous work showing the patchy nature of Hector's dolphin distribution (Dawson and Slooten, 1988). Research at Banks Peninsula on the alongshore range of individually identified dolphins has shown a mean alongshore range of about 31 km (SE=2.43; Bräger et al., 2002). Despite wide-ranging surveys over 13 years, the most extreme sightings of any individual were 106 km apart. These data indicate very high site fidelity and indicate that even small-scale discontinuities in distribution may be long lasting. Lack of extensive movement along-shore, and hence limited contact with neighboring populations, is likely to be the mechanism by which Hector's dolphin has become segregated into genetically distinct populations (Pichler et al., 1998; Pichler and Baker, 2000).

The new abundance data, in combination with the genetic data indicating segregation of Hector's dolphin into four populations (Pichler and Baker, 2000) and modeling work indicating that the species is in decline in most of its range owing to bycatch in gill nets (Martien et al., 1999; Slooten et al., 2000), underscore the urgent need for better information on bycatch rates.

Despite strong evidence of bycatch throughout the species' range, observer coverage sufficient to estimate bycatch has been achieved only in one area (Canterbury) for one fishing season (1997–98; Baird and Bradford, 2000). During this season six Hector's dolphins were observed entangled in commercial gill nets (a further two were caught but released alive), resulting in a bycatch estimate of 17 individuals (Starr[3]). One mortality was observed in a trawl net, but very low observer coverage prevented any calculations of overall trawl bycatch (Baird and Bradford, 2000). No attempt was made to assess bycatch in recreational gillnetting during this period, but during a more recent summer (2000–01) five Hector's dolphin mortalities occurred in gill nets that were probably set by recreational fishermen (Department of Conservation and Ministry of Fisheries, 2001). It is not reasonable to assume that all mortalities in recreational gillnets are detected. In our opinion it is likely that combined commercial and recreational gillnet bycatch off Canterbury is about 15–30 individuals per year.

Hector's dolphin abundance on the north, east, and south coasts of the South Island estimated from the surveys reported in the present study is 1880 individuals (CV=15.7%). Hector's dolphins are more common on the

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[3] Starr, P. 2000. Comments on "Estimation of the total bycatch of Hector's dolphins (*Cephalorhynchus hectori*) from the inshore trawl and setnet fisheries off the east coast of the South Island in the 1997–98 fishing year." Unpublished paper presented to Conservation Services Levy Working Group, 28 p. Department of Conservation, P.O. Box 10-420 Wellington, New Zealand.

Table 4

Corrected abundance estimates (only strata with sightings are listed). Number of sightings represents only those made in that stratum and used for density estimation. The number used for estimating effective half strip width.(ESW) differs because it includes sightings from extra transects in areas of similar exposure and transects repeated on the same day (and hence not true replicates for the purposes of estimating density).

Survey zone	Stratum	No. of sightings	ESW (m) (n, CV%)	$N_{(c)}$ (CV%)	Lower 95% CI	Upper 95% CI
Motunau to Timaru (1997–98)	Akaroa harbor	56	275 (71, 22.6)	62 (33.9)	32	121
	Other harbors and bays	8	275 (71, 22.6)	14 (67.5)	3	79
	Banks Peninsula Marine Mammal Sanctuary (BPMMS) (excluding harbors and bays)	62	261 (75, 10.3)	821 (22.1)	535	1258
	<4 nmi offshore, to the north and south of BPMMS	19	261 (75, 10.3)	300 (36.5)	133	679
Timaru to Long Point (1998–99)	Timaru–Long Point (excluding Te Waewae Bay)	13	268 (121, 10.5)	310 (28.4)	201	478
	Te Waewae Bay	14	268 (121, 10.5)	89 (32.4)	36	218
Motunau to Farewell Spit (1999–2000)	Queen Charlotte Sound	3	214 (70, 20.2)	20 (100.5)	4	110
	Cloudy and Clifford Bay	13	277 (89, 6.1)	162 (55.4)	56	474
	Cape Campbell–Motunau	5	277 (89, 6.1)	102 (55.2)	34	305
Total				1880 (21.3)	1246	2843

South Island west coast, where an aerial survey of similar design resulted in an estimate of 5388 (CV=20.6%; Slooten et al., in press). Thus Hector's dolphin abundance in South Island waters is estimated at 7268 individuals (CV=15.8%). The North Island subspecies of Hector's dolphin, now considered critically endangered (IUCN[4]) remains to be surveyed quantitatively.

The new abundance estimates provide an empirical basis from which to calculate levels of take that would still allow the currently depleted populations to recover (e.g., Wade, 1998). These levels of take should be seen as short-term targets for bycatch reduction in gill and trawl nets. For the management of Hector's dolphin to be put on a rational basis, a more comprehensive and wide-ranging assessment of bycatch, including statistically robust observer programs in coastal fisheries, is urgently needed.

Acknowledgments

Literature cited

Baird, S. J., and E. Bradford.
  2000.   Estimation of the total bycatch of Hector's dolphins (*Cephalorhynchus hectori*) from the inshore trawl and setnet fisheries off the east coast of the South Island in the 1997–98 fishing year, 28 p. Published client report on contract 3024, funded by Conservation Services Levy, Department of Conservation, Wellington.   Web site: http://csl.doc.govt.nz/CSL3024.pdf.   [Accessed 8 March 2001.]

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[4] IUCN. 2000. IUCN red list of threatened species. International Union for Conservation of Nature and Natural Resources. Species Survival Commission. [Available at www.redlist.org.]

Baker, A. N., A. N. H. Smith, and F. B. Pichler.
  2002.   Geographical variation in Hector's dolphin: recognition of a new subspecies of *Cephalorhynchus hectori*.   J Roy. Soc. N.Z. 32:713–727.
Barlow, J.
  1988.   Harbor porpoise, *Phocoena phocoena*, abundance estimation for California, Oregon, and Washington: I. Ship surveys.   Fish. Bull. 86:417–432.
  1995.   The abundance of cetaceans in California waters. Part 1: Ship surveys in summer and fall of 1991.   Fish. Bull. 93:1–14.
Bräger, S., S. M. Dawson, E. Slooten, S. Smith, G. S. Stone, and A. Yoshinaga.
  2002.   Site fidelity and along-shore range in Hector's dolphin, an endangered marine dolphin from New Zealand.   Biol. Conserv. 108:–287.
Buckland, S. T., D. R. Anderson, K. P. Burnham, and J. L. Laake
  1993.   Distance sampling: estimating abundance of biological populations, 446 p.   Chapman and Hall, New York, NY.
Buckland, S. T., and B. J. Turnock.
  1992.   A robust line transect method.   Biometrics 48: 901–909.
Carretta, J. V., B. L. Taylor, and S. J. Chivers.
  2001.   Abundance and depth distribution of harbor porpoise (*Phocoena phocoena*) in northern California determined from a 1995 ship survey.   Fish. Bull. 99:29–39.
Dawson, S. M., and E. Slooten.
  1988.   Hector's Dolphin *Cephalorhynchus hectori*: distribution and abundance.   Rep. Int. Whal. Comm. (special issue) 9:315–324.
  1993.   Conservation of Hector's dolphins: the case and process which led to establishment of the Banks Peninsula Marine Mammal Sanctuary.   Aquat. Cons. 3:207–221.
Dawson, S. M., E.. Slooten, F. Pichler, K. Russell, and C. S. Baker.
  2001.   North Island Hector's dolphins are threatened with extinction.   Mar. Mamm. Sci. 17:366–371.
Department of Conservation and Ministry of Fisheries.
  2001.   Hector's dolphin and setnetting Canterbury Area: a paper for public comment, 9 p.   [Available from Ministry of Fisheries, Private Bag 1926, Dunedin, New Zealand.]
Gormley, A.
  2002.   Mark-recapture abundance estimation in marine mammals.   M.S. thesis., 105 p.   Univ. Otago, Dunedin, New Zealand.
IWC (International Whaling Commission).
  1994.   Report of the International Whaling Commission workshop and symposium on the mortality of cetaceans in passive fishing nets and traps.   Rep. Int. Whal. Comm. (special issue)15, 629 p.
Lerczak, J. A., and R. O. Hobbs.
  1998.   Calculating sighting distances from angular readings during shipboard aerial, and shore-based marine mammal surveys.   Mar. Mamm. Sci. 14:590–599.
Martien, K. K., B. L. Taylor, E. Slooten, and S. M. Dawson.
  1999.   A sensitivity analysis to guide research and management for Hector's dolphin.   Biol. Conserv. 90:183–191.
Palka, D. L., and P. S. Hammond.
  2001.   Accounting for responsive movement in line transect estimates of abundance.   Can. J. Fish. Aquat. Sci. 58(4):777–787.
Pichler, F., and C. S. Baker.
  2000.   Loss of genetic diversity in the endemic Hector's dolphin due to fisheries-related mortality.   Proc. Roy. Soc. (Lond), Series B. 267:97–102.
Pichler, F. B., S. M. Dawson, E. Slooten, and C. S. Baker.
  1998.   Geographic isolation of Hector's dolphin populations described by mitochondrial DNA sequences.   Cons. Biol. 12:676–682.
Slooten, E., and S. M. Dawson.
  1994.   Hector's Dolphin.   *In* Handbook of marine mammals, vol V (Delphinidae and Phocoenidae) (S. H Ridgway and R. Harrison, eds.), p. 311–333.   Academic Press. New York, NY.
Slooten, E., S. M. Dawson, and W. J. Rayment.
  In press.   Aerial surveys for coastal dolphins: Abundance of Hector's dolphins off the South Island west coast, New Zealand.   Mar. Mamm. Sci. 20(3).
Slooten, E., D. Fletcher, and B. L. Taylor.
  2000.   Accounting for uncertainty in risk assessment: Case study of Hector's dolphin mortality due to gillnet entanglement.   Cons. Biol. 14:1264–1270.
Turnock, B. J., S. T. Buckland, and G. C. Boucher.
  1995.   Population abundance of Dall's porpoise (*Phocoenoides dalli*) in the Western North Pacific Ocean.   Rep. Int. Whal. Comm. (special issue) 16:381–397.
Wade, P.
  1998.   Calculating limits to the allowable human-caused mortality of cetaceans and pinnipeds.   Mar. Mamm. Sci. 14:1–37.