Status, ecology and conservation of Irrawaddy dolphins (*Orcaella brevirostris*) in Malampaya Sound, Palawan, Philippines

Brian D. Smith[*], Isabel Beasley[#], Mariel Buccat[+], Victor Calderon[+], Roderick Evina[+], Joseph Lemmuel de Valle[+], Angela Cadigal[+], Emmalyn Tura[+] and Zhuljakim Visitacion[+]

Contact e-mail: bsmith@wcs.org

ABSTRACT

A geographically isolated population of Irrawaddy dolphins was recently discovered in Malampaya Sound, Palawan, Philippines. Line-transect surveys conducted in April-November 2001 covered 884km of trackline in the entire Sound and resulted in a total population estimate of 77 individuals (CV = 27.4%), confined to the inner portion (133.7km^2). For all Irrawaddy dolphin sightings, where ecological data were collected ($n = 48$), the mean temperature was 30.2°C, depth 6.5m, salinity 28.3ppt and turbidity 2.2NTUs. Significantly higher turbidity, lower salinity and shallower depth were recorded in the inner Sound compared to adjacent waters. Bottlenose dolphins *Tursiops* sp. (probably *truncatus*) were observed in waters just outside of where Irrawaddy dolphins were recorded. During the study, at least two Irrawaddy dolphins were accidentally killed in bottom-set nylon gillnets used to catch crabs, locally called *matang quatro*. Reports from local fishermen also indicated that as many as three additional animals may have been killed in these nets during the same period. These findings strongly suggest that the Irrawaddy dolphin population in Malampaya Sound is in immediate danger of extirpation due to low numbers, limited range and high mortality. This is the only known population of the species in the Philippines and the nearest known other population is in northern Borneo, some 550km to the south. Recommendations for conserving the population include that: (1) socioeconomic alternatives be developed to promote the conservation goal of reducing the incidence of dolphin entanglement in *matang quatro* gillnets; (2) gillnet free zones be established in core areas of dolphin distribution; (3) Irrawaddy dolphins be promoted as a flagship species of environmental health in the Sound; (4) a long-term programme be established to monitor the dolphin population; and (5) additional investigations be conducted to determine if Irrawaddy dolphins occur in other areas of the Philippines.

KEYWORDS: IRRAWADDY DOLPHIN; SURVEY-VESSEL; ABUNDANCE ESTIMATE; INCIDENTAL CATCHES; GILLNETS; ASIA; CONSERVATION; PHOTO-ID; HABITAT

INTRODUCTION

Irrawaddy dolphins (*Orcaella brevirostris*) are among the cetaceans at greatest risk of population extirpation and perhaps species extinction. They are patchily distributed in shallow, nearshore tropical and subtropical marine waters of the Indo-Pacific, from northeastern Australia in the south, north to the Philippines (Dolar *et al.*, 2002) and west to northeastern India (Stacey and Leatherwood, 1997; Stacey and Arnold, 1999). Their marine distribution is concentrated in estuaries and semi-enclosed water bodies (i.e. bays and sounds), generally adjacent to mangrove forests. Freshwater populations occur in three river systems: the Mahakam of Indonesia; the Ayeyarwady (formerly Irrawaddy) of Myanmar (formerly Burma); and the Mekong of Laos, Cambodia and Vietnam. Irrawaddy dolphins also occur in partially isolated brackish or fresh-water bodies, including Chilka Lake in India and Songkhla Lake in Thailand.

Little information is available on the range-wide status of Irrawaddy dolphins. Recent surveys indicate declines in the range and abundance of the Mekong and Mahakam freshwater populations (Smith and Jefferson, 2002). The latter was classified as Critically Endangered in the 2000 IUCN Red List (Hilton-Taylor, 2000) after surveys recorded only a few tens of dolphins, confined to a 152km segment in the middle reaches of the river (Kreb, 2000).

Interest in Irrawaddy dolphins of Malampaya Sound can be attributed to the fact that it is the only known population of the species in the Philippines and because threats from accidental killing in fishing gear, habitat degradation (both in the estuary and surrounding watershed), and possible prey depletion from over-fishing and the destruction of fish spawning grounds are prevalent and expected to increase (Dolar *et al.*, 2002). The species was first documented as occurring in Malampaya Sound during an investigation of dugongs (*Dugong dugon*) in 1986 (Kataoka *et al.*, 1995). The first dedicated cetacean survey of the area, conducted in June-July 1999, recorded 17 sightings during 230 linear km of search effort and calculated a mean encounter rate of 7.4 dolphins/100km (SE = 2.9) and mean group size of 5.3 dolphins (SE = 1.1; Dolar *et al.*, 2002). All sightings were made in shallow waters (76% less than 6m deep) of the inner Sound.

Malampaya Sound was proclaimed a protected area in June 2000 (National Integrated Protected Areas Programme (NIPAP), 2000). The Sound encompasses approximately 230km^2, divided into inner and outer portions by 13 rocky islands (Fig. 1). Maximum depth is about 16m in the inner Sound and 46m in the outer Sound. The surrounding landscape is characterised by high hills, with altitudes ranging from 100-500m, and dominated by the 1,013m tall Mt Capoas on the western side. Steep topography and a highly indented shoreline contour, with many small and large bays, coves and inlets create complex wind patterns that vary greatly according to area, season and time of day (due to convection forces). Seasonal climate is largely determined by the southwest monsoon rains, with the wettest months in July-September. Freshwater inflows come from

[*] *Wildlife Conservation Society, Asia Freshwater and Coastal Cetacean Program, 27/16 Soi Naya, Moo 1 Muang, Rawai, Phuket 83130, Thailand.*
[#] *School of Tropical Environment Studies and Geography, James Cook University, Townsville, Queensland 4811, Australia.*
[+] *Kabang Kalikasan Ng Pilipinas (World Wildlife Fund – Philippines), 23 Maalindog Street, U.P. Village, Diliman, Quezon City 1101, Philippines.*

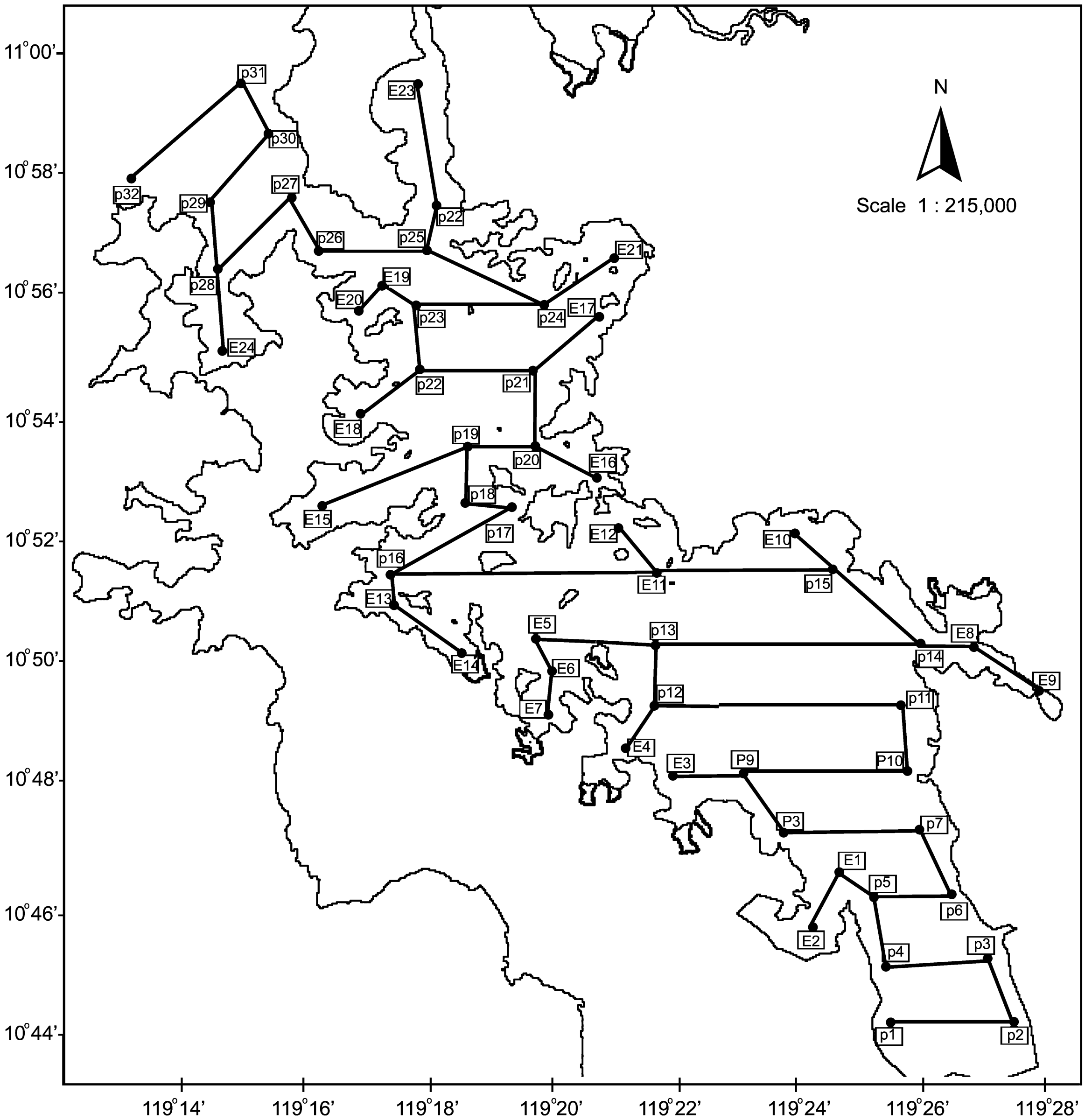

Fig. 1. Map of Malampaya Sound showing tracklines for dolphin surveys conducted during April-November 2001.

numerous rivers draining into the inner Sound and extensive mangroves dominate the shore in this area. Fishing is the principal source of income and employment, with at least 5,000 fishermen dependent on at least 60 commercially valuable species. However, fish production within the Sound is believed to have declined dramatically in recent years (NIPAP, 2000).

MATERIALS AND METHODS

Line-transect surveys

Line-transect surveys were conducted from April to November 2001 to assess the abundance and distribution of Irrawaddy dolphins. During the surveys, three observers stood watch at all times, one stationed on each of the port and starboard sides, searching with handheld binoculars (Fujinon 7×50 with an internal compass) and naked eye from the beam to about 10° past the bow, and one in the centre searching by naked eye, except to focus on visual cues (e.g. splashes), in about a 20° cone in front of the bow. The centre observer also served as the data recorder. Five observers rotated through these positions approximately every 30 minutes or at the end of transect line endpoints, giving each observer about an hour of rest for every 90-minute period spent actively searching for dolphins (i.e. on-effort). The vessel crew and resting observers were instructed to keep dolphin sightings a secret until the on-effort observers saw them, or the entire dolphin group passed well behind the vessel beam. When this happened, the sighting was classified as off-effort and not included in the line-transect analysis. The survey vessel was a 10.3m double outrigger, with a beam of 2.3m on main hull, and equipped with a 40hp four-cylinder diesel motor. The eye-height of the centre observer was about 3.8m above the waterline, while the eye heights of the port and starboard observers were about 3.2m above the waterline. A Global Positioning System (GPS) was used to determine position, speed, course and the distance covered along the trackline. These data, along with Beaufort sea state and the presence or absence of fog and/or rain, were recorded on a standardised effort log. Data entries were made after all observer rotations and any substantial change in vessel course or sighting conditions.

The transect lines were designed to systematically search the entire Sound according to the most unbiased route (i.e. one that avoids following environmental contours; Fig. 1). The transect line was divided into legs, which generally followed a ladder-like grid, with the primary or longer legs normally running east to west across the Sound, ending about 1km from shore, and spaced 2km apart. Connecting doglegs were oriented as close as possible to perpendicular in orientation to the primary legs. Extension legs were added to some endpoints (and occasionally in the middle of longer legs) so that waters within bays and behind islands could also be visually searched. Extension legs were followed to the end while on-effort but line-transect data were not collected during the return trip. The 2km spacing between the primary legs was based on prior experience with the sighting characteristics of Irrawaddy dolphins (see Smith *et al.*, 1997; Smith and Hobbs, 2002), published accounts of their generally cryptic surfacing behaviour (see Mörzer Bruyns, 1966; Stacey and Arnold, 1999) and distance estimates made during practice surveys, which indicated that the dolphins would probably not be observed at a distance greater than 1,000m during Beaufort 3 sea state conditions.

There was some unavoidable compromise in the trackline design since the doglegs did indeed follow shoreline contours, but this potential bias was balanced by the need to search areas hidden within the numerous small bays and inlets that could not be searched from the primary or extension legs. Nevertheless, potential sighting biases along the dogleg lines were evaluated by examining possible clumping in dolphin distribution close to the shoreline and by comparing encounter rates recorded along the dogleg lines versus those along the primary and extension lines.

Vessel speed was maintained at 8-10km h^{-1}. Survey effort was generally stopped when sea state conditions became greater than Beaufort 3, or when rain or fog affected ability to detect dolphin surfacings at a distance of less than 1km. The decision to suspend survey effort when sea state conditions were greater than Beaufort 3 was made after considering the generally cryptic surfacing behaviour of Irrawaddy dolphins, the strong spatial heterogeneity of wind patterns in the Sound and the improbability of making a sufficient number of sightings in Beaufort 4 conditions or greater to allow stratification according to sea state. Simply deleting the survey effort conducted while sighting conditions were poor from the line-transect analysis, as done by Jefferson *et al.* (2002) for estimating the abundance of finless porpoises (a cetacean that exhibits somewhat similar inconspicuous surfacing behaviour), could have resulted in a severely biased abundance estimate. Spatial coverage would have been uneven (especially near Mt Capoas where convection winds often created poor survey conditions), while dolphin distribution within the Sound may have been clumped. When the sea state exceeded Beaufort 3 along one transect line, acceptable conditions were sometimes found along another line located in the lee of the wind. The vessel returned to the earlier line when the wind abated.

The protocol for suspending survey effort when sea state conditions were greater than Beaufort 3 was unavoidably violated due to poor weather during the three August surveys, but a single composite survey was put together *post hoc* from transect lines covered in good conditions. Effort from the first August survey was mostly used, but transect lines surveyed in Beaufort 4 conditions during this survey were substituted with those that were surveyed in Beaufort 3 or less conditions during the second or third surveys, whichever one was completed first.

The survey programme was designed to obtain coverage during the pre-monsoon, monsoon (southwest) and post-monsoon seasons. Considering that previous studies had only observed Irrawaddy dolphins in the inner portion of the Sound (south of the P15-P16 transect line; Fig. 1) and the importance of maximising the number sightings to ensure a reasonably precise abundance estimate, the survey protocol was established to cover the entire Sound (*ca* 154 linear km) during the first survey of each season. Then during subsequent surveys of that season, if no sightings were made north of the P15-P16 transect line, searching would only occur along transect lines of the inner portion and a 4km wide buffer strip extending to the north (*ca* 101 linear km, inclusive of transect lines P16-P17-P18-P19 and E15-P19-P20-E16; Fig. 1).

When a dolphin group was sighted, information was recorded on a standardised sighting form that included entries for geographic position, time of sighting, Beaufort sea state and estimated distance and relative angle from the bow to the dolphin group. Distances were estimated by eye (see below for details on training exercises to reduce distance estimation biases) and relative angles were determined from the difference between the vessel course (as measured by the GPS in magnetic degrees) and the bearing to the dolphin group (as measured by the internal compass in the binoculars). The recorder also occasionally checked the vessel bearing according to the internal compass in handheld binoculars to ensure that there were no major discrepancies between the two readings. Survey effort was then suspended and the vessel turned towards the dolphins to obtain a more accurate estimate of group size and to take photographs of individuals for identification purposes (see below). After finishing these tasks, the vessel returned off-effort (i.e. while not actively searching for new dolphins) to the position where it left the trackline; movements of the sighted dolphin group were tracked during this time to avoid double counting the animals when search effort was resumed.

For oceanic line-transect surveys of cetaceans, sighting distances are generally estimated using the number of binocular reticles from the animal cluster to the horizon (e.g. see Kinzey and Gerrodette, 2001). Because the horizon was not visible in the Sound, this technique could not be used. Following the example of Jefferson and Leatherwood (1997) and Jefferson *et al.* (2002), a laser range finder (*Bushnell Yardage Pro* 1000) was used in training observers to more accurately estimate sighting distances by eye and to investigate potential distance estimation biases. Although a laser range finder cannot obtain a reading from a surfacing dolphin, training exercises were conducted using other objects on the water, such as fishing gear, boats and buoys. One observer estimated the distance to an object while another simultaneously recorded the actual distance with the laser range finder. The results were kept secret until after 20 trials, when the information was shared so that observers could improve the accuracy of their future estimates. These exercises were periodically conducted for all observers throughout the survey programme.

Dolphin density (D) and its associated coefficient of variation (CV) were estimated using the program DISTANCE 3.5 and according to the line-transect formula in Buckland *et al.* (1993):

$$\hat{D} = \frac{n\,\hat{f}(0)\,\hat{E}(s)}{2L} \text{ and } C\hat{V} = \sqrt{\frac{\hat{\mathrm{var}}\,(n)}{n^2} + \frac{\hat{\mathrm{var}}\,[\hat{f}(0)]}{[\hat{f}(0)]^2} + \frac{\hat{\mathrm{var}}\,[\hat{E}(s)]}{[\hat{E}(s)]^2}} \quad (1)$$

where n = number of on-effort sightings; $f(0)$ = probability density value at zero perpendicular distance; $E(s)$ = unbiased estimate of group size; L = length of transect lines surveyed; and var = variance. Abundance (N) was then calculated from the density estimate (D) according to: $\hat{N} = \hat{D} * A$, where A = size of the survey area. Data from all surveys were pooled to estimate *f(0)*. This value was then used to calculate abundance estimates stratified according to pre-monsoon, monsoon and post-monsoon seasons and a composite estimate for all three seasons combined. All other parameters and their associated variances were estimated empirically.

The Distance program plotted histograms of sighting distances and comparisons were made of the Akaike's Information Criterion (AIC) for uniform, hazard-rate and half-normal models to determine which one most closely fit the empirical data. Various levels of truncation for dolphin groups sighted at distances far from the trackline were experimented with and the level that resulted in the best fit with the theoretical model was chosen. One of the primary assumptions of line-transect theory is that all objects have the same probability of detection at the same distance. Since this assumption is violated when surveying species that occur in clusters (because large clusters have a higher probability of being detected far from the trackline in comparison to smaller ones), a size bias correction was used for *E(s)*, calculated from the log of estimated group sizes regressed against the detection probability estimated from the fit of the selected model to the pooled data (see Buckland *et al.*, 1993).

Dive and surface time study

A major assumption of line transect theory is that all animals are observed on the trackline (i.e. $g(0) = 1$; see Buckland *et al.*, 1993). This assumption is often violated when surveying cetaceans because the animals may be submerged or behave cryptically when they are within the observers' field of view, or the observers' attention may be directed elsewhere. This potential bias was investigated using radial sighting distances recorded during the surveys and group dive and surface times collected from land-based observation sites.

Four land-based observation sites were chosen (Malampaya Sound Protected Area Office (PAO), Agpay, Logpond, and Pancol; see Fig. 2), based on the criteria that they overlooked a variety of habitat types where dolphins were frequently found. Two observers searched for dolphins from these sites (not concurrent with the vessel surveys), one with binoculars and the other by naked eye, alternating every 10 minutes to reduce fatigue. Once a dolphin group was sighted, using a stopwatch, observers recorded group dive and surface times. Groups were defined as any cluster of dolphins observed in apparent association, moving in the same direction and often, but not always, engaged in the same activity. Dive times were defined as the interval when no animals were visible at the surface for longer than one second, while surface times were defined as the interval in between.

Photo-identification

In addition to conducting line-transect surveys, the feasibility of using photo-identification for assessing the Malampaya Irrawaddy dolphin population was investigated. When lighting conditions were adequate and the animals were within a reasonable range of the vessel (e.g. < 25m) photographs were taken of the dorsal fin and flukes with a *Canon* EOS-5 QD camera, equipped with a *Canon* EF 100-400mm F4.5-5.6 lens and image stabiliser. Ektachrome Elite 100 ASA colour slide film was used.

In photo-identification studies, dolphins are typically identified from nicks, scars, scratches, deformities and pigmentation features located on or in the region of the dorsal fin (e.g. Würsig and Jefferson, 1990). However, during preliminary surveys some of these features were also observed on the flukes, which sometimes became visible when the dolphins made steep inclined dives while foraging. Since the dorsal fins often appeared to have few marks that would allow individuals to be identified, attempts were made to photograph and use distinguishing features on the flukes for identification purposes.

Photographs were classified as poor (dolphin either not in view or the image not of sufficient quality for identifiable features to be discerned if they were present), moderate (dorsal fin or flukes could be seen clearly and, if present, obvious diagnostic features would probably be discerned) and good (dorsal fin or flukes could be seen and, if present, subtle diagnostic features would probably be discerned). Moderate and good slides were then classified according to the presence of recognisable distinguishing marks: absent (no features available for identification), fair (sufficient marks discerned for probable identification) and excellent (marks could be easily distinguished for reliable identification).

Ecology

During line transect surveys, information was collected on water surface temperature (with a standard laboratory thermometer), salinity (with an *Atago* Hand Refractometer), turbidity (with a *Hanna* HI 93703 Microprocessor Turbidity Meter) and depth (with a *Speedtech* Hand-held 400 KHs depth sounder) at all leg endpoints and at the locations where dolphins occurred. Samples were taken at leg endpoints due to convenience (as these generally corresponded with our observer rotations). It is recognised that this may have caused a small bias toward nearshore conditions. Factorial ANOVAs were used to investigate the effect of area (inner and outer Sound) and season (pre-monsoon, monsoon and post-monsoon) on temperature, salinity, depth and turbidity. A similar factorial design was also used to test for differences among the ecological samples collected at transect line waypoints in the inner Sound and those collected at the locations of dolphin sightings.

RESULTS

Distribution and abundance

During three surveys of the entire Malampaya Sound (total area 230.7km^2), one each in the pre-monsoon, monsoon and post-monsoon seasons, Irrawaddy dolphins were observed only in the inner portion (total area 133.7km^2; Fig. 2). Sightings of the species were confined to the same area during the other four surveys (two each during the pre-monsoon and post-monsoon seasons), which included search effort in the inner Sound and buffer zone (24.0km^2) only. Altogether 50 Irrawaddy dolphin sightings were recorded during survey effort used for the line-transect analysis (mean group size = 5.3, SD = 2.9, range = 1-15). Six sightings were made of bottlenose dolphins *Tursiops* sp. (probably *truncatus*; mean group size = 5.1, SD = 3.2, range = 1-9), 2 and 4 in the monsoon and post-monsoon seasons respectively. All were in the outer Sound and buffer zone, with the exception of one that was in the far northern portion of the inner Sound.

Based on seven complete surveys of the inner Sound conducted during the pre-monsoon, monsoon and post-monsoon seasons, covering a total of 578.1km of trackline, the overall abundance of Irrawaddy dolphins was estimated, using a Fourier series uniform + cosine model (see Burnham *et al.*, 1980), to be 77 individuals

(CV = 27.4%). This figure was similar to the seasonally stratified estimates (67, CV = 38.6%; 78, CV = 78.1% and 81, CV = 31.7% for pre-monsoon, monsoon and post-monsoon seasons, respectively, and well within their 95% confidence intervals; Table 1). There were no significant differences among the stratified estimates (Chi-square Prob = 0.5149).

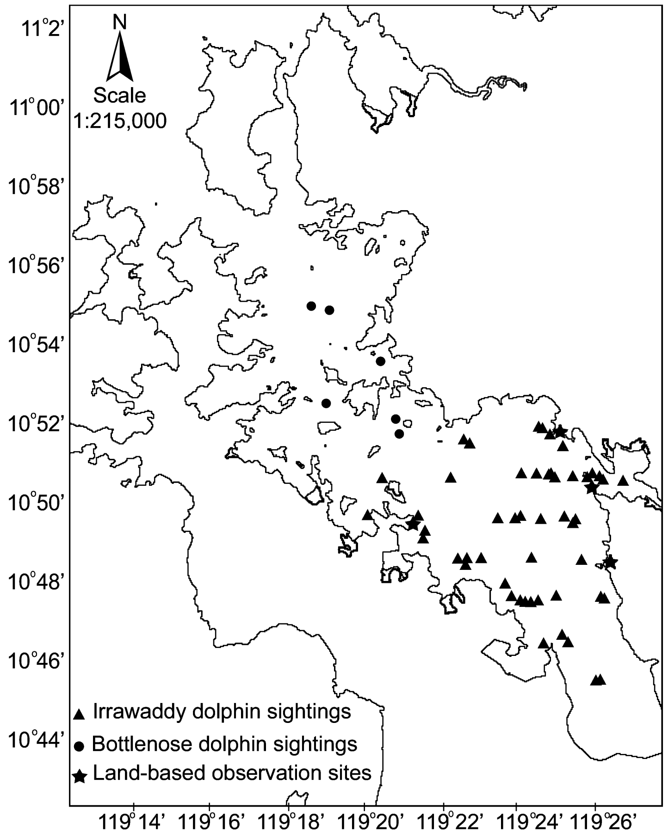

Fig. 2. Map of Malampaya Sound showing the locations of Irrawaddy and bottlenose dolphin sightings and land-based observation sites.

Photo-identification

A total of 524 dorsal fin photographs of Irrawaddy dolphins were taken during 29 encounters. Overall photographic quality was low, with 91.0% classified as poor, 5.3% as moderate and 3.7% as good. The large number of poor photographs resulted from the dolphins being too far away, or the image being out of focus. Of the 44 good and moderate quality photographs, 38.6% had no distinguishing marks, 11.4% were classified as fair and 50.0% as excellent. From the fair and excellent photographs, 17 Irrawaddy dolphins were identified. Two of these (OBRE03 and OBRE05) were re-identified once each during the study. In addition, 27 fluke photographs were taken. Photographic quality was similarly low, with 81.5% classified as poor, 11.1% as moderate and 7.4% as good. Two of these had fair distinguishing marks and three excellent, resulting in identifications of four individuals. No re-identifications were made from fluke photographs.

Ecology

For all Irrawaddy dolphin sightings in which ecological data were collected ($n = 48$) the mean surface temperature was 30.2°C (SD = 1.3, range = 27.0-32.5), depth 6.5m (SD = 3.1, range = 1.5-15.1), salinity 28.3ppt (SD = 4.7, range = 14.0-34.0) and turbidity 2.2 nephelometric turbidity units, NTUs (SD = 2.2, range = 0-9.6). These values were not significantly different from those collected at transect line waypoints in the inner Sound (DF = 247), although temperature was almost significant at Prob. = 0.0848, with slightly lower temperatures recorded at the survey waypoints. There were significant differences, however, in the ecological data collected in the inner Sound during different seasons for temperature (F = 28.83, Prob. = 0.0000; Tukey-Kramer Multiple-Comparison (TKMC) Prob. < 0.05 for Apr = Aug, Apr = Oct/Nov, Apr = Aug and Oct/Nov) and salinity (F = 21.70, Prob. = 0.000; TKMC Prob. < 0.05 for Apr and Aug = Oct/Nov, Apr = Aug and Oct/Nov) (Table 2, Fig. 3).

For the five bottlenose dolphin sightings where ecological data were collected, the mean temperature was 29.7°C (SD = 0.3; range = 29–30.0), depth 23.9m (SD = 7.0; range = 14.4–31.7), salinity 30.6ppt (SD = 1.5; range = 29.0-32.0) and turbidity 0.2NTUs (SD = 0.2; range = 0-0.5).

For surveys of the entire Sound (one each during April, August and October), there were significant differences (DF = 158) between ecological data collected in the inner and outer Sound (the latter inclusive of the buffer zone) for depth (F = 164.54, Prob. = 0.0000), salinity (F = 19.27, Prob. = 0.0000) and turbidity (F = 21.53, Prob. = 0.0000), with depth and salinity greater in the outer Sound and turbidity greater in the inner Sound. There were also (Table 2, Fig. 3) significant differences among seasons (DF = 2, 153) for temperature (F = 4.29, P = 0.0154, TKMC Prob < 0.05 for Apr = Aug, Apr = Oct, Apr = Aug and Oct) and salinity (F = 15.03, P = 0.0000; TKMC Prob. < 0.05 for Apr = Oct, Apr = Aug and April and Aug = Oct).

DISCUSSION

Distribution

The absence of Irrawaddy dolphin sightings in the outer Sound and buffer zone, during this study and others (see Dolar *et al.*, 2002, and unpublished reports of WWF-Philippines), and the close agreement among

Table 1

Composite and seasonally stratified abundance estimates of Irrawaddy dolphins in Malampaya Sound from line transect surveys conducted during April-November 2001 (*ESW* = effective strip width, S = mean groups size, *N* LCI and *N* UCI = Estimated population size at lower and upper 95% confidence intervals, respectively).

Survey	*n*	*L* (km)	*ESW*	*S*	*E(s)*	*D*	%CV	*N* LCI	*N* UCI	*N*
Pre-monsoon (Apr)	11	243.7	274.9	5.27	6.07	0.4983	38.57	32	139	67
Monsoon (Aug)	4	78.7	274.9	5.27	6.07	0.5612	78.14	18	311	74
Post-monsoon (Oct/Nov)	14	255.7	274.9	5.27	6.07	0.6045	31.67	44	139	81
Composite for all lines	30	578.1	274.9	5.27	6.07	0.5730	27.43	45	130	77
Composite for primary and extension lines	26	480.2	301.1	5.27	5.78	0.5209	29.93	39	124	70

Table 2

Summary of ecological parameters recorded during surveys in the Inner Sound, buffer zone, Outer Sound and for Irrawaddy dolphin sightings (PPT=parts per thousand, NTU=nephelometric turbidity units). Parameters are only reported for the first August survey due to poor weather conditions that compromised survey effort during subsequent surveys of the monsoon season.

Survey/sample	N	Temp (°C)				Depth (M)				Salinity (PPT)				Turbidity (NTU)			
		Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD	Min	Max
14-17 Apr																	
Inner Sound	24	30.0	1.4	28.0	33.0	6.4	4.8	0.7	15.7	31.8	1.3	29.0	34.0	3.7	4.6	0.0	20.7
Buffer zone	5	30.2	1.1	29.0	31.0	12.7	6.0	8.5	22.9	31.4	0.5	31.0	32.0	0.3	0.3	0.0	0.7
Outer Sound	20	30.0	1.1	28.0	31.5	28.0	11.8	9.8	49.1	32.1	1.3	29.0	34.0	0.3	0.3	0.0	0.8
Dolphins	3	31.5	1.8	30.0	33.5	6.0	4.7	1.0	10.4	31.0	3.6	27.0	34.0	3.9	3.8	1.2	8.2
19-20 Apr																	
Inner Sound	27	31.4	0.9	30.0	33.0	6.6	4.6	0.9	15.4	31.3	1.5	27.0	36.0	3.6	5.0	0.4	25.2
Buffer zone	6	30.3	1.3	29.0	32.0	18.1	7.2	9.5	26.5	32.7	1.2	31.0	34.0	0.5	0.8	0.1	2.0
Dolphins	5	31.6	0.5	31.0	32.0	6.4	2.7	4.1	10.8	31.0	0.7	30.0	32.0	1.5	0.7	0.8	2.5
22-24 Apr																	
Inner Sound	29	31.2	0.9	28.5	33.0	6.2	4.5	0.8	15.3	31.7	1.8	25.0	34.0	3.6	3.6	0.0	12.5
Buffer zone	5	31.1	0.5	30.5	32.0	17.6	8.1	8.6	25.6	32.4	0.5	32.0	33.0	1.1	0.9	0.5	2.6
Dolphins	9	31.2	0.7	30.0	32.5	5.0	1.9	2.3	7.7	32.0	2.1	27.0	34.0	2.9	1.9	1.1	6.1
8-11 Aug																	
Inner Sound	30	29.3	1.0	27.0	31.0	6.2	4.4	1.3	11.7	29.1	5.9	5.0	33.0	4.5	8.5	0.3	46.8
Buffer zone	6	29.2	0.6	28.0	29.5	19.9	6.5	11.7	27.1	29.8	7.3	15.0	34.0	4.4	8.9	0.6	22.7
Outer Sound	20	29.8	0.9	28.0	31.5	30.1	12.3	10.1	49.7	32.9	1.3	30.0	34.0	0.9	0.9	0.1	3.0
Dolphins	8	29.6	1.4	27.0	31.0	7.1	3.1	2.1	11.8	30.0	4.0	21.0	32.0	2.3	3.1	0.4	9.2
8-11 Oct																	
Inner Sound	29	29.2	1.0	28.0	31.0	5.8	4.5	0.8	14.5	27.4	2.7	21.0	31.0	2.9	5.1	0.0	22.6
Buffer zone	6	29.6	1.4	28.0	31.5	17.4	7.2	9.1	26.5	29.2	0.8	28.0	30.0	0.1	0.2	0.0	0.4
Outer Sound	21	29.7	1.1	27.5	31.0	26.9	15.1	6.1	51.2	31.0	2.1	25.0	34.0	0.0	0.0	0.0	0.0
Dolphins	7	29.6	0.9	28.0	30.5	6.8	2.9	2.4	10.9	28.3	1.7	26.0	30.0	0.7	0.9	0.0	1.9
13-16 Oct																	
Inner Sound	30.0	28.6	0.9	27.0	31.0	6.3	4.6	0.9	16.1	24.8	6.0	3.0	30.0	5.1	12.7	0.0	68.0
Buffer zone	6.0	29.6	0.5	29.0	30.0	17.0	7.3	9.2	26.5	29.7	0.8	29.0	31.0	0.0	0.0	0.0	0.0
Dolphins	8.0	29.1	0.8	28.0	30.0	6.0	3.2	3.2	11.0	25.1	3.5	18.0	29.0	2.2	2.5	0.0	6.3
6-12 Nov																	
Inner Sound	21.0	29.9	1.5	26.8	33.0	7.2	4.5	1.6	14.8	25.2	6.9	8.0	33.0	2.4	4.5	0.0	17.9
Buffer zone	6.0	29.4	0.8	28.5	30.5	16.6	7.1	8.5	25.6	31.8	1.3	30.0	33.0	0.3	0.7	0.0	1.7
Dolphins	8.0	29.5	1.1	27.5	31.0	8.6	3.9	3.9	15.1	21.4	3.6	14.0	25.0	2.6	3.0	0.1	9.6

abundance estimates from surveys conducted during pre-monsoon, monsoon and post-monsoon seasons, strongly suggest that the population is resident within the inner Sound. A plot of all on-effort sightings appears to show a slight affinity of the animals for shoreline areas (Fig. 2), but dolphins were also frequently observed in mid-water, often in close proximity to *bukatots* (fixed lift nets operating from a semi-permanent structure made of wood pilings). These structures probably aggregate fish and therefore may actually enhance mid-water habitat for the dolphins.

Evaluation of precision and biases of abundance estimates

An evaluation of the assumption that $g(0) = 1$ (i.e. all dolphins are detected on the trackline) was conducted using dive and surface time information from land-based observations and the radial distance estimates to dolphin clusters from the survey vessel. A mean dive time of 11.9sec ($n = 5{,}510$, SD = 18.6, range = 1-259) and mean surface time of 1.3sec ($n = 5510$, SD = 0.7, range = 1-14) were recorded from 90 dolphin groups at four observation sites. The mean group size was 4.7 dolphins (SD = 1.9; range = 2-10), which is close to the mean group size recorded during the line-transect surveys (5.3; interestingly the same figure was reported by Dolar *et al.*, 2002) and there was no significant difference between the two samples (Mann-Whitney Test Prob. = 0.2876).

According to distance estimation data from the surveys, a decline in sighting frequencies occurs past 466.7m (Fig. 4). The mean vessel speed for all seven surveys was 8.8 km/hr or 2.44 m/sec. This means that, on average, it took 190.6sec, to cover the distance where it can be assumed that dolphins available on the surface would have a high probability of being detected (otherwise there would have been a decline in the sighting rate before this distance). A cumulative frequency distribution of dive times indicates that, while surveying along 466.7m of trackline, 99.9% of dolphin groups would be available for detection at least once (only seven dives were recorded longer than 190.6sec.) and, on average (according to the mean dive time plus the mean surface time (13.2sec) for a complete dive cycle), during 17 occasions for a total of 22.1sec on the surface. The dolphins would also be available for detection during the same number of surfacings and for the same amount of time while inside the second 466.7m increment (i.e. between 466.7m-933.4m distance from the vessel) where the proportion of animals detected was still relatively high (85.7%). Although the behaviour of Irrawaddy dolphins was relatively inconspicuous, their relatively short surfacing intervals ensured a very high probability of detection on the trackline (at least during Beaufort 3 sea state conditions or less; see below). The short surfacing intervals recorded during this study should not be extrapolated to Irrawaddy dolphins in others areas. The results may have been related to the shallow depth of the inner Sound. Stacey and

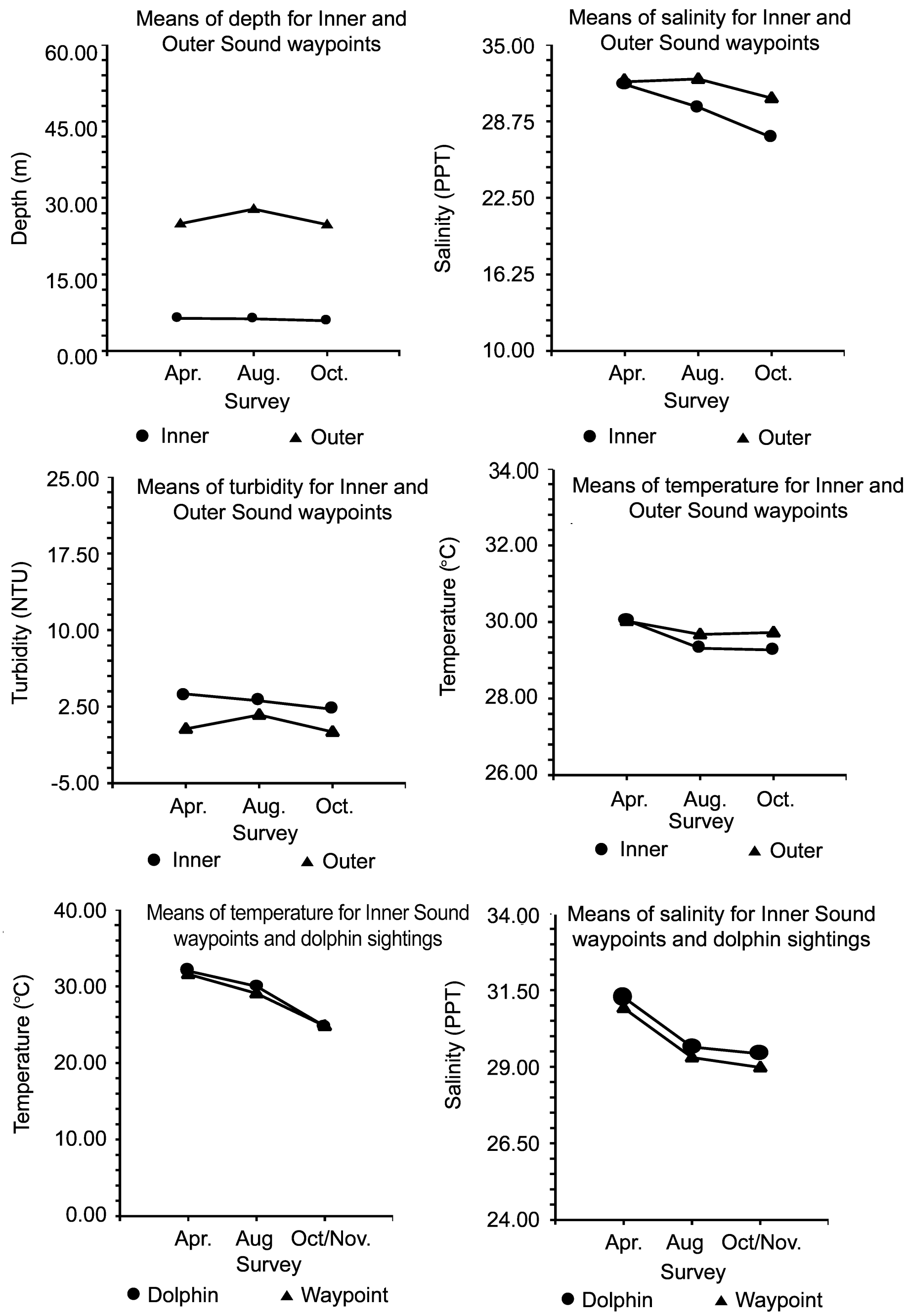

Fig. 3. Plots of means for ecological data collected in the inner and outer sounds (top four plots) and at waypoints and dolphin sightings in the inner sound only (bottom two plots).

Hvenegaard (2002) recorded much longer dive times for the species in the Mekong River, Laos (mean = 115.3sec, SD = 59.1, n = 277), where the mean depth of dolphin habitat was 18.4m.

Due to the large number of sightings made at perpendicular distances relatively close (0-200) and far (401-800m) from the trackline, but lack of sightings at middle distances (201-400; Fig. 5), a high truncation level (40%) was necessary to obtain a good fit of the theoretical model (Fig. 6). Three possibilities can explain these field results. The first one relates to differences in the ability to detect the animals according to their behaviour. The dolphins often behaved in an extremely cryptic manner, barely breaking the surface with the top of their head. While exhibiting this behaviour they could generally only be detected at close distances. During other times, while feeding and socialising, the animals were much more visible, showing their dorsal fins and flukes and sometimes splashing. They could then easily be observed from far distances (especially considering their short group dive intervals; see above). Another explanation was that observers alternated between searching with binoculars and naked eye. The tendency while searching with binoculars was to emphasise detecting dolphins at far distances, while observers searching with naked eye were probably unable to detect dolphins at distances greater than 200m. This may have resulted in a lack of searching coverage at middle distances (i.e. > 200m and < 400m), although this problem would be expected to have a more profound effect on radial sighting distances than on perpendicular sighting distances. A third explanation could have been avoidance behaviour at far distances and attraction behaviour at close distances. However, this is considered unlikely since the dolphins were only observed reacting evasively to the survey vessel when approached quite close (e.g. < 25m) to take photographs (and never when a depth reading was taken with the

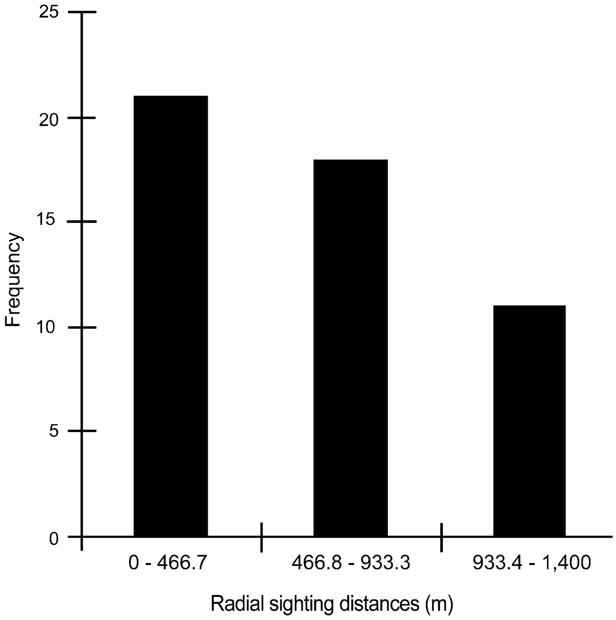

Fig. 4. Histogram of sighting frequencies divided into three equal radial distance increments.

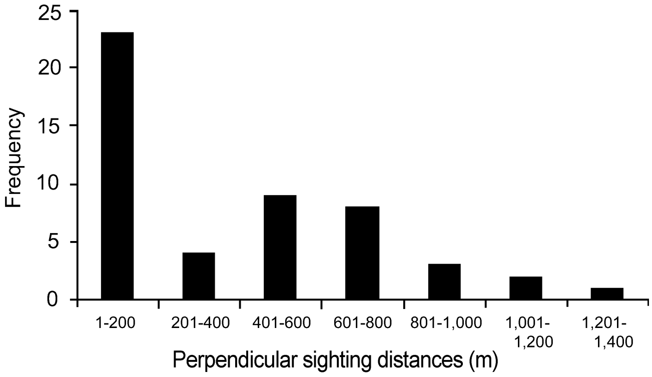

Fig. 5. Frequency of perpendicular sighting distances recorded during dolphin surveys ($n = 50$).

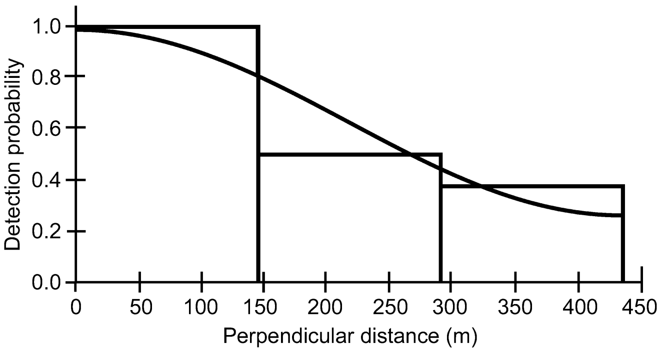

Fig. 6. Detection probability plot for the composite abundance estimate from all transect lines in the inner Sound.

hand-held 400kHz depth sounder) and they were never observed to be attracted to the boat, except occasionally when the motor stopped and the vessel drifted while not conducting survey effort. A similar lack of evasive or attraction behaviour was observed while collecting dive and surface time data from the land-based observation sites. Regardless of the factors that contributed to the poor fit of the theoretical model without substantial truncation, the level of precision for the composite abundance estimate was sufficient to determine that the population size is dangerously small.

The accurate estimation of sighting distances is one of the primary assumptions of line-transect theory (Buckland *et al.*, 1993). A regression of estimated versus measured distances to objects on the water showed a significant relationship between the two ($F = 745.7$, $Prob. = 0.0000$, $R^2 = 0.7104$) and a small negative bias among distances measured > 100m (Fig. 7). If it is assumed that observers estimate distances to dolphins with the same degree of accuracy as the objects that were used for the distance estimation experiment, then the abundance estimate of 77 dolphins may have a slight positive bias. The distance estimates could have been calibrated to dolphin clusters recorded during the surveys, but the high residual variance among the estimated values in the experiment, and the fact that the measured values were only on average 4.8% greater than the estimated ones, implied that the resultant correction factor would probably be unreliable and the difference negligible. A large portion of the residual variance and negative bias could be accounted for by differences in the distance estimation abilities of individual observers. Perhaps not surprisingly, those observers who estimated distances most accurately in the experiment also had the highest sighting rates during the dolphin surveys. This may partially mitigate the apparent negative bias indicated in the experiment (which used pooled data from all observers). It also suggests that calibrations should be considered for individuals, rather than for the entire observer group. This was not possible due to small sample sizes relative to the number of individuals who participated as observers.

Due to the apparent slight clumping of dolphin sightings in nearshore areas and the possibility that including dolphins observed along the dogleg transect lines could positively bias the resulting abundance estimate, a separate estimate using only data from the primary and extension transect lines was calculated. While this estimate was slightly lower (65 dolphins, CV = 30.1%), the general overlap in its range (95% CI = 36-116) versus the estimate that includes all transect lines (95% CI = 45-130) and the broad agreement between overall encounter rates for the dogleg lines (0.0725 sightings km^{-1}; $n = 7$) versus the primary and extension lines (0.0895 sightings km^{-1}; $n = 43$) indicates that including sightings from the dogleg lines would not cause a significant bias. The similarity in sighting rates, combined with the extreme shoreline complexity of the Sound, also implied that deleting sightings made on dogleg lines would unnecessarily reduce sample size and possibly introduce a slight negative bias, because substantial areas of dolphin distribution in waters not visible from the primary or extension lines would be excluded from the analysis.

To a certain extent, distance sampling can compensate for animals missed due to poor sighting conditions (Jefferson and Leatherwood, 1997), however, Beaufort sea state can severely affect line-transect abundance estimates, especially with cryptic species; see for example Palka (1996). Measures were taken to minimise this bias by generally suspending survey effort when sea state conditions were greater than Beaufort 3 or, during the monsoon season, patching together data from three surveys to achieve a single complete survey conducted in Beaufort 3 conditions or less. In the latter case, due to the strong spatial heterogeneity of wind patterns (especially affected by convection forces near Mt Capoas) and the possibility that a clumped distribution of dolphins within the Sound could lead to a biased abundance estimate, for the line-transect analysis it was considered important to use only data from complete surveys conducted in Beaufort 3 conditions or less. The wisdom of both of these measures was reinforced by the fact that no Irrawaddy dolphin sightings were made during the survey effort conducted in Beaufort 4 conditions (93.8km in the inner Sound – only 16.2km of these data were used in the line-transect analysis). In comparison, the overall encounter rate for survey effort conducted in Beaufort 3 conditions or less was 0.0865 sightings km^{-1}. If the detection rate for survey effort conducted in Beaufort 4 conditions was comparable, six or seven sightings should have occurred during the 93.8km of survey effort conducted during these conditions.

The distribution of survey effort in the inner Sound used for the abundance estimate was 11.6%, 19.1%, 31.4%, 15.9% and 2.8% for Beaufort sea states of 0-4, respectively. Although there were insufficient data to stratify abundance estimates according to sighting conditions, a chi-squared test showed no significant difference between the actual and expected number of sightings according to sea state (Prob. = 0.4048, DF = 4).

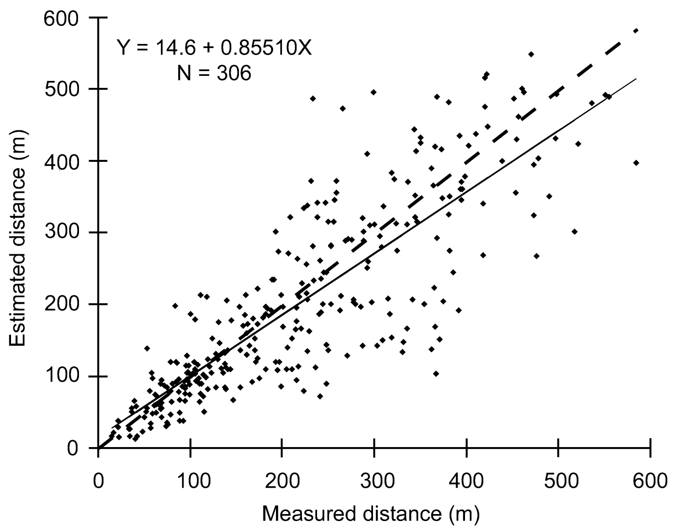

Fig. 7. Estimated sighting distances to fixed objects versus measured distances from laser range-finder readings. The solid line fits the empirical data while the dashed line is theoretical assuming no bias.

Feasibility of photo-identification

Preliminary indications are that photo-identification is a feasible research technique for studying Irrawaddy dolphins in Malampaya Sound (also see Parra and Corkeron, 2001) but that its application will be labour intensive and fairly expensive. Problems with this technique included the lack of distinguishing marks, cryptic surfacing behaviour and avoidance of the research vessel by the dolphins upon close approach. Stacey and Hvenegaard (2002) reported similarly poor results from photoidentification efforts on Irrawaddy dolphins in the Mekong River of Laos; out of 629 photographs taken, only 7.5% were of sufficient quality to distinguish identifiable marks and less than one-quarter of these exhibited marks that could be used to identify individuals.

While line-transect surveys proved to be a much more useful technique for assessing Irrawaddy dolphin abundance, photo-identification can provide valuable data on other aspects of the dolphin population that are difficult (or impossible) to obtain using other methods. Home range, habitat use and social affiliations can be investigated according to re-identifications and the frequencies at which individuals occur in particular locations and in the same groups (see Würsig and Jefferson, 1990 and other papers in Hammond *et al.*, 1990). Knowledge of these parameters is important for developing effective strategies to reduce human-dolphin conflicts and for evaluating the effects of dolphin kills. For example, the death of a single individual can have severe negative consequences on the survivability of other individuals in complex cetacean societies (especially females with dependent calves), but these issues are difficult to assess without information on individuals within the population.

Environmental preferences

Results of the ecological investigation indicate the restricted environmental preferences of Irrawaddy dolphins in the Sound, which probably explains their confinement to the inner portion. Interspecific competition with bottlenose dolphins occurring in the buffer zone and outer Sound may also play a role. Irrawaddy dolphins appear to be particularly adapted to shallow inshore waters, characterised by relatively low salinity and high turbidity, in comparison to areas located closer to open water (i.e. the buffer zone and outer Sound).

These results reinforce the notion of the population's vulnerability to local disturbances. Unlike some other dolphin species, whose environmental preferences are more flexible and thereby allow them to occupy a greater range of habitat (e.g. bottlenose dolphins; see Shane *et al.*, 1986; Wells and Scott, 2002), Irrawaddy dolphins appear to be obligatorily adapted to relatively rare and circumscribed ecological conditions – deep pools of large rivers and protected nearshore marine environments (including appended lakes) with substantial freshwater inputs (see reviews in Stacey and Leatherwood, 1997; Stacey and Arnold, 1999; Smith and Jefferson, 2002). High salinity, however, does not appear to have direct adverse effects, as there was no difference between the mean salinity values recorded for the outer and inner portions of the Sound during April (when freshwater inputs were particularly low), while the dolphins still remained confined to the latter area. This implies that the affinity of the dolphins for low salinity waters is likely due to ecological preferences (probably related to prey), rather than to physiological intolerance to high salinity conditions.

Mortality and population viability

Estimating human-caused mortality of dolphins in the Malampaya population is an extremely difficult task due to the sporadic reporting of accidental kills. The situation is confounded by the value of dolphin carcasses for human consumption, which ensures that most deaths probably go unreported, or that reports are received well after the remains of the animal have been disposed. Between February and August 2001, two dolphins were confirmed accidentally killed in bottom-set nylon gillnets used for catching crabs – locally known as *matang quatro* nets. Unconfirmed reports from fishermen indicate that three additional dolphins may have been killed in gillnets during this seven-month period. For small cetaceans, it is generally recommended that yearly removals should not exceed 1-2% of the overall population size (Wade, 1998). Using a minimum estimate of two dolphins killed per year, considered extremely conservative, this works out to be 2.6% of the population, according to the best estimate of abundance made during line transect surveys

(77 dolphins). It has been argued that, when evaluating the potential effects of mortality on dolphin populations, the minimum abundance estimate, rather than the best, should be used for calculating mortality rates (e.g. see Taylor and Gerrodette, 1993). Using the minimum abundance estimate (45 dolphins), the yearly mortality rate would then be 4.4% of the population size. This figure should probably still be considered low because it considers only the two confirmed kills made during seven months.

Considering that the small size of the Malampaya population already means it is vulnerable to extirpation, due to demographic stochasticity, inbreeding depression and catastrophic environmental and epizootic events (see Soulé and Wilcox, 1980; Gilpin and Soulé, 1986; Lynch, 1996), the present rate of accidental killing will almost certainly lead to its extirpation unless immediate action is taken to reduce or eliminate human-caused deaths.

Conservation

The Irrawaddy dolphin population in Malampaya is the only one known of the species in the Philippines and its extirpation would represent a significant loss of cetacean diversity in the region. Of paramount importance is to eliminate, or drastically reduce, dolphin mortality from entanglement in gillnets. Similar to the situation of the vaquita, a critically endangered porpoise isolated in the upper Gulf of California, Mexico (see Rojas-Bracho and Taylor, 1999; Rosel and Rojas-Bracho, 1999; Taylor and Rojas-Bracho, 1999), this will require action at a socio-economic level, as well as assistance from cetacean and fishery scientists (Reeves *et al.*, 2003). A number of high priority recommendations relevant to conservation are discussed below.

(1) Developing socio-economic alternatives to dramatically reduce or eliminate the incidence of dolphin entanglement in matang quatro *gillnets*

The economic status of fishermen in Malampaya Sound is generally poor (see National Integrated Protected Areas Programme (NIPAP), 2000), and the *matang quatro* fishery for crab provides substantial local employment. This fishery requires little monetary investment and is therefore an attractive option for the most economically impoverished of local fishermen. It would be unacceptable (and probably counter-productive) to prohibit this fishing technique without providing alternatives that ensure an equal or greater income. While more information is needed about the feasability of alternative employment options and the details of the *matang quatro* crab fishery (e.g. number of fishermen and income generated by the fishery, differences between the efficiency of traps versus *matang quatro* nets, market trends for crabs in the Philippines, etc.), immediate action must be taken to provide alternative employment if Irrawaddy dolphins are to be conserved in Malampaya Sound (Reeves *et al.*, 2003). Alternatives could include developing the green mussel fishery, improving the efficiency of crab pots, promoting grow-out pens for groupers and other economically valuable fishes and developing community-based ecotourism.

(2) Establishing gillnet free zones in core areas of dolphin distribution

While providing employment alternatives for gillnet fishermen is clearly the most important first measure that should be taken, without the ultimate closure of this fishery, conservation prospects for the dolphins are poor. A likely scenario is that, as current gillnet fishermen take up other occupations, immigrants or a new generation of local villagers, will begin using *matang quatro* nets again. Concurrent with promoting employment alternatives should be regulations prohibiting gillnet use. This should proceed in a step-wise fashion, starting in areas that are easily monitored and where the dolphins occur most often. As more gillnet fishermen choose to pursue other forms of employment, more areas would then become closed. The success of this approach will depend on the close cooperation of regulating authorities, conservation organisations and local fishing communities, and enforcement to ensure that everyone abides by the same rules. A major challenge will be to convince local people that gillnet free zones offer benefits to them and thus deserve their support. Such benefits might include revenues from nature tourism, permission to use non-destructive fishing techniques and the fact that protection of fish breeding or nursery areas can enhance fisheries outside the zone (see Reeves *et al.*, 2003).

(3) Promoting Irrawaddy dolphins as a flagship species for environmental stewardship of Malampaya Sound

The presence of Irrawaddy dolphins is a strong reminder that judicious stewardship is critical to preserve an environment that supports abundant and diverse fish and crustacean communities. Promoting Irrawaddy dolphins as a flagship species will require strengthening community awareness programmes, with an emphasis on educating local people on regulations regarding resource use and on promoting the linkages between dolphin conservation and sustainable fisheries.

Research and monitoring

In addition to direct conservations measures, it is important that research is continued, particularly in terms of monitoring whether conservation measures are working. Some high priority recommendations is this regard are discussed below.

(1) Strengthening the capacity of local scientists

Education and infrastructure development are required so that local scientists and resource managers can provide the stimulus and expertise for dolphin conservation. It is essential that local workers develop the ability to independently devise, conduct, analyse and effectively communicate the results of research and monitoring activities.

(2) Establishing a long-term programme to monitor the dolphin population

Monitoring abundance, distribution and mortality is critical for measuring the efficacy of conservation measures. Line-transect surveys have been shown to be an appropriate technique for assessing dolphin distribution and abundance in the Sound. It is important that the standardised survey protocol developed during the present study be consistently applied and that effort and observations be painstakingly documented. The low precision, typical of wildlife studies investigating small populations, can dramatically affect the ability to achieve statistical significance with inter-survey comparisons (Taylor and Gerrodette, 1993). This means that several surveys will need to be conducted each year and that an appropriate α probability level should be based on the consequences of failing to reject the null hypothesis of no trend when it is indeed false (see Gerrodette, 1987; 1993) — probably set at not less than 0.10, considering the small size of the Malampaya population. Monitoring mortality will also be essential. Researchers face formidable challenges in this area because fishermen may be reluctant to report accidental kills, due to fear of prosecution or future restrictions on fishing activities. They also have a strong motivation to keep dolphin carcasses, due to their value as a source of meat. Scientists should establish a community-based reporting network to encourage fishermen to report incidental catches and recover carcasses for examination and necropsy. The fishermen should be assured that they will not be prosecuted for reporting accidental kills and a campaign should be initiated for convincing local villagers to utilise alternative food sources.

(3) Continuing photo-identification efforts for both Irrawaddy and bottlenose dolphin in selected areas
As new identifications are made and previously identified animals are re-identified, the photo-identification catalogue compiled during this study will become a more valuable tool for guiding management considerations. Due to the difficulties of applying this technique to Irrawaddy dolphins in the Sound, a relatively small area accessible by small paddleboat should be targeted for emphasis (e.g. nearshore waters between Old Guinlo and Agpay). This will provide initial information on habitat use and site fidelity, which can be followed up by more extensive photo-identification efforts as the photo-id catalogue is enlarged and as per the availability of funds and trained personnel.

(4) Conducting additional investigations to determine if Irrawaddy dolphins occur in other areas of the Philippines
The small size of the Irrawaddy dolphin population in Malampaya Sound means that it is extremely vulnerable to extirpation. The loss of genetic variation in small populations can result in decreased fecundity and reproductive success, smaller offspring size, slower growth rates and reduced survivorship (Ralls *et al.*, 1986). The prospects for survival of the population would be greatly enhanced by the mixing of individuals from one or more other populations, even if this occurred only very occasionally (assuming that the new immigrants were adapted to similar environmental conditions; see Lynch, 1996). Both for evaluating the long-term viability of the Malampaya population and considering the need for protecting other populations, should the species be found to occur elsewhere in the Philippines, a concerted effort should be made to identify other areas in Palawan and adjacent islands (e.g. in the Calamian Group to the north and Balabac Island and the Pangutaran Group to the south) where Irrawaddy dolphins might occur. This investigation should initially be conducted using interview surveys (see Aragones *et al.*, 1997) and by selecting potential sites, based on knowledge of the oceanography, bathymetry and ecological features where Irrawaddy dolphins are already known to be present (see above and reviews in Stacey and Leatherwood, 1997; Stacey and Arnold, 1999), with follow-up at-sea surveys conducted using standardised techniques.

(5) Investigating the population identity of Irrawaddy dolphins in Malampaya Sound
Wildlife conservation should aim to preserve the full range of genetic variation within species. The nearest area where another population of Irrawaddy dolphins is known to occur is northern Borneo, some 550km to the south. Evidence from skull morphology suggests that there are probably two sub-species or species of *Orcaella*, one occurring in South and Southeast Asia and another in Australia and Papua New Guinea (Beasley *et al.*, 2002). Throughout their range, there may also be numerous genetically distinct populations. Information on the population identity of Irrawaddy dolphins in Malampaya Sound would be useful for evaluating the viability and evolutionary significance of the population (see Dizon *et al.*, 1992). Population identity should be investigated using both morphologic and genetic techniques.

ACKNOWLEDGEMENTS

This project was a component of the Malampaya Sound Ecological Studies Project implemented by Kabang Kalikasan Ng Pilipinas (World Wildlife Fund – Philippines). We acknowledge the assistance with logistics given by the project manager, Terry Aquino, and staff of the Malampaya Sound Protected Area Office and KKP offices in Puerto Princessa and Quezon City. We appreciate the help of the captain and crew of our research vessel, Cipriano Galang, Greg Gacoba and Jessie Macahipay and local villagers of Malampaya Sound. We also thank Dr Thomas Jefferson (Southwest Science Fisheries Center, National Marine Fisheries Service, NOAA, P.O. Box 271, La Jolla, CA 92038 USA) and two anonymous reviewers for providing valuable comments on an earlier draft of the manuscript. The Wildlife Conservation Society provided funding to the first author during the later stages of preparing this paper.

REFERENCES

Aragones, L.V., Jefferson, T.A. and Marsh, H. 1997. Marine mammal survey techniques applicable in developing countries. *Asian Mar. Biol.* 14:15-39.

Beasley, I., Arnold, P. and Heinsohn, G. 2002. Geographic variation in skull morphology of the Irrawaddy dolphin, *Orcaella brevirostris* (Owen in Gray, 1866). *Raffles Bull. Zool.* Supplement 10:15-34.

Buckland, S.T., Anderson, D.R., Burnham, K.P. and Laake, J.L. 1993. *Distance Sampling: Estimating Abundance of Biological Populations*. Chapman and Hall, New York and London. xii+446pp.

Burnham, K.P., Anderson, D.R. and Laake, J.L. 1980. Estimation of density from line transect sampling of biological populations. *Wildl. Monogr.* 72:1-202.

Dizon, A.E., Lockyer, C., Perrin, W.F., DeMaster, D.P. and Sisson, J. 1992. Rethinking the stock concept: a phylogeographic approach. *Conserv. Biol.* 6(1):24-36.

Dolar, M.L.L., Perrin, W.F., Gaudiano, J.P., Yaptinchay, A.A.S.P. and Tan, J.M.L. 2002. Preliminary report on a small estuarine population of Irrawaddy dolphins *Orcaella brevirostris* in the Philippines. *Raffles Bull. Zool.* Supplement 10:155-60.

Gerrodette, T. 1987. A power analysis for detecting trends. *Ecology* 68(5):1,364-72.

Gerrodette, T. 1993. TRENDS: Software for a power analysis of linear regression. *Wildl. Soc. Bull.* 21:515-6.

Gilpin, M.E. and Soulé, M.E. 1986. Minimum viable populations: Processes of species extinction. pp. 19-34. *In:* M.E. Soulé (ed.) *Conservation Biology: the science of scarcity and diversity*. Sinauer Associates, Sunderland, Massachusetts. 584pp.

Hammond, P.S., Mizroch, S.A. and Donovan, G.P. (eds.). 1990. *Report of the International Whaling Commission (Special Issue 12). Individual Recognition of Cetaceans: Use of Photo-Identification and Other Techniques to Estimate Population Parameters*. International Whaling Commission, Cambridge, UK. [vi]+440pp.

Hilton-Taylor, C. 2000. *2000 IUCN Red List of Threatened Species*. IUCN/SSC, Gland, Switzerland and Cambridge, United Kingdom. i-xviii+64pp.

Jefferson, T.A. and Leatherwood, S. 1997. Distribution and abundance of Indo-Pacific humpbacked dolphins (*Sousa chinensis* Osbeck, 1765) in Hong Kong waters. *Asian Mar. Biol.* 14:93-110.

Jefferson, T.A., Hung, S.K., Law, L., Torey, M. and Tregenza, N. 2002. Distribution and abundance of finless porpoises in Hong Kong and adjacent waters of China. *Raffles Bull. Zool.* Supplement 10:43-56.

Kataoka, T., Mori, T., Wakai, Y., Palma, J., Yaptinchay, A.A., DeVeyta, R. and Trono, R. 1995. Dugongs of the Philippines: a report of the joint dugong research and conservation program. Aquarium and the Pawikan Conservation Project, May 1995 (unpublished). 167pp. [Available from: Toba Aquarium, 3-3-6 Toba, Mie, Japan].

Kinzey, D.P. and Gerrodette, T. 2001. Conversion factors for binocular reticles. *Mar. Mammal Sci.* 17(2):353-61.

Kreb, D. 2000. Density and abundance of Irrawaddy dolphins, *Orcaella brevirostris*, in the Mahakam River of East Kalimantan, Indonesia. A comparison of survey techniques. *Raffles Bull. Zool.* Supplement 10:85-96.

Lynch, M. 1996. A quantitative-genetic perspective in conservation issues. pp. 471-5. *In:* J.C. Avise and J.L. Hamrick (eds.) *Conservation Genetics*. Chapman and Hall, New York. i-xvii+512pp.

Mörzer Bruyns, W.J.F. 1966. Some notes on the Irrawaddy dolphin, *Orcaella brevirostris* (Owen, 1866). *Z. Saugetierkd* 31:367-70.

National Integrated Protected Areas Programme (NIPAP). 2000. Malampaya Sound Protected Land and Seascape, General Management Plan, Volume 1. (Unpublished). [Available from: Department of Environment and Natural Resources, Protected Areas and Wildlife Bureau, Visayas Avenue, Diliman, Quezon City, Philippines].

Palka, D. 1996. Effects of Beaufort sea state on the sightability of harbor porpoises in the Gulf of Maine. *Rep. int. Whal. Commn* 46:575-82.

Parra, G.J. and Corkeron, P. 2001. The feasibility of using photo-identification techniques to study the Irrawaddy dolphin, *Orcaella brevirostris* (Owen in Gray 1866). *Aquat. Mamm.* 27:45-9.

Ralls, K., Ballou, J.D. and Templeton, A. 1986. Estimates of lethal equivalents and the cost of inbreeding in mammals. *Conserv. Biol.* 2:185-93.

Reeves, R.R., Smith, B.D., Crespo, E.A. and Notarbartolo di Sciara, G. 2003. *Dolphins, Whales and Porpoises −2002-2010 Conservation Action Plan for the World's Cetaceans*. IUCN/SSC Cetacean Specialist Group, Gland and Cambridge. xi+139pp.

Rojas-Bracho, L. and Taylor, B.L. 1999. Risk factors affecting the vaquita (*Phocoena sinus*). *Mar. Mammal Sci.* 15(4):974-89.

Rosel, P.E. and Rojas-Bracho, L. 1999. Mitochondrial DNA variation in the critically endangered vaquita *Phocoena sinus* Norris and Macfarland, 1958. *Mar. Mammal Sci.* 15(4):990-1003.

Shane, S.H., Wells, R.S. and Würsig, B. 1986. Ecology, behavior and social organization of the bottlenose dolphin: a review. *Mar. Mammal Sci.* 2(1):34-63.

Smith, B.D. and Hobbs, L. 2002. Status of Irrawaddy dolphins *Orcaella brevirostris* in the upper reaches of the Ayeyarwady River, Myanmar. *Raffles Bull. Zool.* Supplement 10:67-74.

Smith, B.D. and Jefferson, T.A. 2002. Status and conservation of facultative freshwater cetaceans in Asia. *Raffles Bull. Zool.* Supplement 10:173-87.

Smith, B.D., Thant, U.H., Lwin, J.M. and Shaw, C.D. 1997. Investigation of cetaceans in the Ayeyarwady River and northern coastal waters of Myanmar. *Asian Mar. Biol.* 14:173-94.

Soulé, M.E. and Wilcox, B.A. (eds.). 1980. *Conservation Biology, An Evolutionary-Ecological Perspective*. Sinauer, Sunderland, Mass. 395pp.

Stacey, P.J. and Arnold, P.W. 1999. *Orcaella brevirostris*. *Mamm. Species* 616:1-8.

Stacey, P.J. and Hvenegaard, G.T. 2002. Habitat use and behaviour of Irrawaddy dolphins (*Orcaella brevirostris*) in the Mekong River of Laos. *Aquat. Mamm.* 28:1-13.

Stacey, P.J. and Leatherwood, S. 1997. The Irrawaddy dolphin, *Orcaella brevirostris*: A summary of current knowledge and recommendations for conservation action. *Asian Mar. Biol.* 14:195-214.

Taylor, B.L. and Gerrodette, T. 1993. The uses of statistical power in conservation biology: the vaquita and northern spotted owl. *Conserv. Biol.* 7:489-500.

Taylor, B.L. and Rojas-Bracho, L. 1999. Examining the risk of inbreeding depression in a naturally rare cetacean, the vaquita (*Phocoena sinus*). *Mar. Mammal Sci.* 15(4):1004-28.

Wade, P.R. 1998. Calculating limits to the allowable human-caused mortality of cetaceans and pinnipeds. *Mar. Mammal Sci.* 14:1-37.

Wells, R.S. and Scott, M.D. 2002. Bottlenose dolphins *Tursiops truncatus* and *Tursiops aduncus*. pp. 122-8. *In:* W.F. Perrin, B. Würsig and J.G.M. Thewissen (eds.) *Encyclopedia of Marine Mammals*. Academic Press, San Diego. i-xxxviii+1414pp.

Würsig, B. and Jefferson, T.A. 1990. Methods of photo-identification for small cetaceans. *Rep. int. Whal. Commn* (special issue) 12:43-52.