Facultative river dolphins: conservation and social ecology of freshwater and coastal Irrawaddy dolphins in Indonesia

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CHAPTER 5

Abundance of freshwater Irrawaddy dolphins in the Mahakam River in East Kalimantan, Indonesia, based on mark-recapture analysis of photo-identified individuals

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One photo-identified individual PM 34 with a distinctively shaped dorsal fin. During early 1999 and mid 2002, a total of 59 individuals were identified.
ABSTRACT

From February 1999 until August 2002 c. 9000 km (840 hours) of search effort and 549 hours of observation on Irrawaddy dolphins (Orcaella brevirostris) were conducted by boat in the Mahakam River in East Kalimantan, Indonesia. Intended goal was to generate an estimate of total population size essential for conservation and management of this threatened freshwater dolphin population. An abundance estimate based on mark-recapture analysis of individuals photographed during separate surveys is presented here. Two different analysis methods, i.e. Petersen and Jolly-Seber methods were employed and compared with each other and with earlier estimates derived from strip-transect analysis and direct counts. These comparisons serve to evaluate the biases of each method and assess the reliability of the abundance estimates. The feasibility of video-identification is also assessed. Total population size calculated by Petersen and Jolly-Seber mark-recapture analysis, was estimated to be 55 (95% CL = 44-76; CV=6%) and 48 individuals (95% CL = 33-63; CV=15%). Estimates based on strip-transect and direct count analysis for one sampling period, which was also included in the mark-recapture analysis, were within the confidence limits of the Jolly-Seber estimate (Ncount = 35 and Nstrip = 43). Calculated potential maximum biases appeared to be small, i.e. 2% of N for Petersen and 10% of N for Jolly-Seber method, which is lower than the associated CVs. Also, a high re-sight probability was calculated for both methods varying between 65% and 67%. Video images were considered a valuable, supplementary tool to still photography in the identification of individual dolphins in this study. For future monitoring of trends in abundance using mark/re-capture analyses, a time interval is recommended between the two sampling periods that is short enough to minimise the introduction of errors due to gains and losses. Also, survey area coverage during photo-identification should be similar to avoid violation of the assumption of equal capture probabilities. The alarmingly low abundance estimates presented here call for immediate and strong action to preserve Indonesia’s only known freshwater dolphin population.

RINGKASAN

Dari Februari 1999 sampai Agustus 2002 kurang lebih 9000 km (840 jam) penelitian dan 549 jam pengamatan lumba-lumba Irrawaddy (Orcaella brevirostris) dilakukan dengan menggunakan kapal di Sungai Mahakam, Kalimantan Timur, Indonesia. Tujuan utamanya untuk menghasilkan suatu perkiraan dari jumlah keseluruhan populasi yang digunakan sebagai bahan untuk perlindungan dan pengelolaan lumba-lumba air tawar dari kepunahan. Perkiraan keadaan yang berlebihan didasarkan pada
INTRODUCTION

Since 1970, photo-identification studies have proven to be a valuable tool in revealing aspects of population dynamics, social organisation, distribution and movement patterns for many species of cetaceans (Whitehead et al., 2000). The technique involves collecting and cataloguing photographs of dolphins with distinctive marks on the dorsal fins, flukes and bodies that allow for identification of individuals. Photo-identification, when seriously attempted, was found feasible for every cetacean species that is in possession of a distinct dorsal fin (Mann, 2000). But the ease of getting good photo-identification results highly varies among species depending on uniqueness of the marks and behaviour of the species. Easily identifiable cetaceans with nearly complete photo-identification databases for certain populations include killer whales, 2000). For most other species, e.g., hump-backed dolphins, Sousa chinensis (Jefferson
Orcinus orca (Baird, 2000) and humpback whales, Megaptera novaeangliae (Clapham, and Leatherwood, 1997; Jefferson, 2000); Pacific white-sided dolphins, Lagenorhynchus obliquidens (Morton, 2001) and northern bottlenose whales, Hyperoodon ampullatus (Gowans and Whitehead, 2001) only a proportion of the population can be reliably identified because not all fins are characteristically marked. Another factor limiting identification is due to the elusive behaviour of some species of dolphins. Photo-identification of Irrawaddy dolphins, Orcaella brevirostris, commonly described as an elusive species (Lloze, 1973; Dhandapani, 1992; Kreb, 1999) required greater effort, but was shown to be feasible for coastal populations in Australia (Parra and Corkeron, 2001). In addition, freshwater populations of Irrawaddy dolphins that are known to occur in only three major river systems, i.e. the Mahakam River in Kalimantan, the Mekong River in Vietnam, Laos and Cambodia and the Ayeyarwady River in Myanmar (Burma) were reported to be visually identifiable, but photo-identification efforts until now were more or less incidental (Stacey, 1996; Smith, 1997; Kreb, 1999). Freshwater dolphin populations in many cases live in a closed system and have no exchange with coastal populations. Thus, photo-identification and subsequent mark-recapture analysis to determine total population size might be feasible. This study reports on photo-identification of a population of Irrawaddy dolphins in the Mahakam River, Indonesia and is the first attempt to provide a catalogue in which most individuals of an entire freshwater Irrawaddy dolphin population are identified.

The Irrawaddy Dolphin Orcaella brevirostris is a facultative freshwater dolphin, occurring both in shallow coastal waters and large river systems in tropical South East Asia and subtropical India (Stacey and Arnold, 1999). Irrawaddy dolphins in Indonesia occur along several coastlines and in one river in East Kalimantan, the Mahakam, where they are referred to as pesut (Kreb, 1999). The species is fully protected by law in Indonesia since 1990 and is adopted as a symbol of East Kalimantan Province. Their IUCN status was raised from ‘Data Deficient’ to ‘Critically Endangered’ based on data related to abundance collected from 1999 until 2000 (Kreb, 2002; Hilton-Taylor, 2000).

The objectives are: to present an estimate of total population size based on photo-identification of individual dolphins by using different mark-recapture methods and to compare these with earlier estimates of abundance from strip-transects and direct counts (Kreb, 2002). In addition, the feasibility of digital video recordings as a tool to identify dolphins is evaluated. This photo-identification study is part of a long-term conservation and research project, begun in 1999 to provide a framework to protect the freshwater Irrawaddy dolphin population in the Mahakam River in East Kalimantan, Indonesia.

SURVEY METHODS

During the study period from February 1999 through August 2002, 12 surveys were conducted. Six extensive monitoring surveys (mean duration 20 days; SD= 4 days) covered the entire distribution range and six (mean duration 12 days; SD = 3 days)
were conducted in areas of high dolphin density (Figure 1). Extensive surveys were conducted with 12-16 m long motorised vessels (between 12 and 21 hp), travelling at an average speed of 10 km/hr. The average observation time and photographic effort during the extensive monitoring surveys was one hour per sighting. Most intensive monitoring surveys involved attempts to follow one group for an entire day, with daily alternation of groups and using a small, motorised canoe with 5hp outboard engine. Photographic effort was spread out over the observation time (average duration 7 hours; range 1.5-13 hours).

Upon sighting, the group was approached to a minimum distance of 30m in order to take photographs and video images. We always tried to take these photos from similar angles, i.e. perpendicularly to the dolphins’ dorsal fin region. In addition, identification marks were recorded on datasheets. For each sighting, the duration, location, group behaviour, group size, group composition and environmental data were collected. Four age classes were defined: i) “neonates” were individuals of less than 1/2 the average length of an adult, which spent all their time in close proximity to an adult and exhibited an awkward manner of swimming and surfacing; ii) “calves” were animals between 1/2 and 3/4 the average length of an adult and which still spent most of their time in close proximity to an adult; iii) “juveniles” were animals of 3/4 the average length of an adult and which swam independently; iv) “adults were individuals larger than an estimated 2 meters in length.

Photographs were made by the author using a Canon EOS 650 camera body with a Sigma 300mm/ f4.0 lens, occasionally attaching a 1.4 teleconverter, effectively making it a 420mm/ f5.6 lens. Manual focus was always used with shutter speeds of 1/250 to 1/1500 of a second. Some 75% of the photo-id images were made with slide films using Sensia Fujichrome 100 ISO and another 25% were made using Fuji Superia 200 ISO print-films. It was attempted to always photograph every individual within the group irrespective of whether they at first sight appeared to have distinct dorsal fin markings or not. Photographs were generally taken perpendicularly to the dolphins’ dorsal fin region. Additionally, drawings of dorsal fins (made by aid of binoculars) were made by observers who did not take photographs. Dolphin age classes were also noted for each drawing. Direct observations and drawings were matched with a field photo-identification catalogue and assigned an existing or new identification code.

One field-assistant was assigned to the task of making simultaneous video footage using a Sony VX 1000 digital camcorder with 10x optical and 20x digital zoom. Nearly always only the 10x optical zoom was employed or better image quality. The autofocus option was usually preferred since manually focusing proved more difficult with the camcorder than with the photo-camera.

Information on the number of dead dolphins during the entire study period and in particular between the two sampling periods, was obtained through our own observations and from local, reliable reporters.
Figure 1. Study area with a) total dolphin distribution area, b) areas of high dolphin density and c) coastal Irrawaddy dolphin area.
ANALYSIS

Photographs and slides were selected by aid of an 8x loupe for their good image quality, i.e. focus, glare, photographic angle, dorsal fin size coverage in image and catalogued on basis of identifiable features. Distinctive features noted included notches, scars and cuts on the dorsal fin and distinct fin shapes. Pigmentation patterns were only secondarily considered if they could be linked to a distinct fin shape. Pigment spots or areas do not occur symmetrically on both sides of the dorsal fin. In addition, it was found that pigmentation patterns on the bodies of dolphins and likely therefore on dorsal fins were not stable during the study period. Each photograph in the photo-identification catalogue corresponded to an identified individual and held information on the date, time and location at which the picture was taken as well as data on group size and composition. Photographs with distinctive features such as scars, cuts and humps on the dolphin’s bodies were also selected, but catalogued under another identification code. Photographs with distinctive body features alone were only used for mark-recapture analysis if they could be linked to an individual, which was already identified based on its dorsal fin. Identifications that were obtained through direct observation and drawings were kept in a separate database file than the photo-identified dolphins. These identifications were not used for the mark-recapture analysis.

For analysis of recorded video-images, each image of a dorsal fin was played in slow-motion and paused. Similar to the photo-identification analysis, only images of good quality were selected. These good images were then compared with individuals from the photo-identification catalogue and these were given an identification code and put into a video-identification catalogue together with related sighting data.

Two estimates of total population size (N) were calculated based on two different mark-recapture analysis methods of photo-identification data. Only sampling periods with extensive area coverage were selected, which were suitable for estimating total population size. The first estimate utilized the Petersen method for closed populations, involving one session of catching and marking and one recapture session. Bailey’s modified estimator was applied for sampling with replacement (Equation 1.1) (Hammond, 1986). Sample periods May/ June 2000 and August 2001 were chosen because the photographic effort (i.e. area coverage) was similar in those periods (Table 1). The second method to estimate total abundance was the Jolly-Seber method for open populations, allowing for gains and losses within the sampling periods. Also, capture histories of each identifiable individual were needed since the method requires both knowledge of the number of animals in each sample that were previously marked and information on the most recent previous sample in which each of them was last trapped. The number of marked individuals in four sampling periods, i.e., October 1999, May/ June 2000, January/ February 2001 and August 2001, with extensive area coverage, were higher than the minimum sample size of 10 marked individuals recommended to overcome imprecision of abundance estimates (Table 1) (Sutherland, 1996). Prior to the calculation of an abundance estimate, a goodness-of-fit test was
applied (Sutherland, 1996) to test if animals differed in capture-probabilities, which may cause a serious bias of the estimate. After testing, three sampling periods were chosen to be appropriate for abundance estimation (see results).

According to the Jolly-Seber method, no estimates of abundance can be calculated for the first and last sampling period and thus only one estimate is derived from the second sampling period (Equation 2.1). For this last method, it was also possible to calculate the proportion of the population surviving (Φ) from the 1st to the 2nd sampling occasion (Equation 2.3). A correction factor was applied to the population estimates of both methods to correct for the proportion of dolphins that are not identifiable (p) (Jefferson & Leatherwood, 1997). These were neonates and calves, which could not be captured properly on photo because their mothers protect them away from the boat and from a good camera angle and because calves often surface very suddenly (high arch dives). The averages of the proportion of neonates and calves encountered during two (Petersen) and three (Jolly-Seber) sampling periods are 10% and 8% respectively, which represent the proportion unidentifiable dolphins (p).

For the Petersen method binomial 95% confidence intervals were calculated for the fraction of marked individuals \( \frac{m_2 + 1}{n_2 + 1} \), which were then applied to the formula in Equation 1.1. to obtain the 95% confidence limits for population size (Krebs, 1999). Jolly-Seber confidence limits were calculated using the formula provided by Manly (1984). Coefficients of variation were calculated for both methods according to the formulas in Equation 1.2 and 2.4. Estimated re-sight probabilities for the Petersen estimator are given by \( \frac{m_2}{m_2 + 1} \) and \( p_2 = \frac{m_2}{n_1} \) and for Jolly-Seber by \( n_i / N_i \), in which \( N_i \) is (only here) the uncorrected abundance estimate for proportion of identifiable dolphins.

\[
\text{Eqn 1.1} \quad N = n_1 \frac{(n_2 + 1)}{(m_2 + 1)(1 - p)} \quad \text{(Petersen method)}
\]

\[
\text{Eqn 1.2} \quad CV(N) = N^{-1} \sqrt{\frac{n_1^2}{(m_2 + 1)^2} \frac{(n_2 - m_2)}{(m_2 + 2)(m_2 + 2)}} + \frac{\text{var}(1 - p)}{(1 - p)^2}
\]

where

- \( n_1 \) = number identified on the first occasion
- \( n_2 \) = total number identified on the second occasion
- \( m_2 \) = number of identified dolphins found on the second occasion
- \( p \) = proportion of unidentifiable individuals

\[
\text{Eqn 2.1} \quad N_i = \frac{M_i (n_i + 1)}{(m_i + 1)(1 - p)} \quad \text{(Jolly-Seber method)}
\]
Mark-recapture analysis of photo-identified Irrawaddy dolphins in the Mahakam

Eqn 2.2
\[ M_i = \frac{m_i + (R_i + 1)z_i}{(r_i + 1)} \]

Eqn 2.3
\[ \Phi_i = \frac{M_i + 1}{(M_i - m_i + R_i)} \]

Eqn 2.4
\[
CV (N_i) = \sqrt{x_i} \cdot \left( \frac{(M_i - m_i + R_i + 1)}{M_i + 1} \right) \left( \frac{1}{(r_i + 1)} - \frac{1}{(R_i + 1)} \right) + \frac{1}{m_i + 1} - \frac{1}{n_i + 1} + \text{var} \left( \frac{1 - p}{1 - p} \right) \]
\[ \log e N_i + 0.5 \log e \left( \frac{0.5 - 3n_i}{8N_i} \right) \]

Where
- \( N_i \): population size at the time of the \( i \)th sample
- \( M_i \): number of marked animals in the population when the \( i \)th sample is taken (excluding animals newly marked in the \( i \)th sample)
- \( n_i \): total number of animals caught in the \( i \)th sample
- \( R_i \): number of animals that are released after the \( i \)th sample
- \( m_i \): number of animals in the \( i \)th sample that carry marks from previous captures
- \( z_i \): number of animals caught both before and after the \( i \)th sample but not in the \( i \)th sample itself
- \( r_i \): number of animals that were released from the \( i \)th and were subsequently recaptured
- \( x_i \): number of samples

Finally, maximum biases that may affect population size estimates for each method were calculated. A maximum bias using Petersons method, which assumes no losses, was calculated by adding the number of dead dolphins (= 3) in between the two sampling periods, to the number of ‘recaptured’ animals during the second sampling period \( (m_{2bias} = m_2 + 3) \). This number was also added to the total number caught on the second occasion \( (n_{2bias} = n_2 + 3) \). When applying this bias one assumes that these dolphins would have been ‘marked’ during the first session and also assumes that they would have been ‘recaptured’ if they hadn’t died.

A maximum bias using Jolly-Seber method was related to the fact that one area was not surveyed during the second sampling period of the three sampling periods in total. This area, which is an area in between two rapids and home to a group of six dolphins, was surveyed only during the first and last sampling period. Two and three new individuals were marked during the first and last sampling period, respectively, without any recaptures. The largest deviation from the abundance estimate would apply for a situation in which we assume that this area would have been surveyed during the second sampling period, which four new individuals would be captured and marked and three of which would be recaptured during the third sampling period.
Chapter 5

This maximum deviation of the estimate is calculated following equation 2 above by adding three individuals to \( r_2 \) (number of marked dolphins in the 2\(^{nd} \) sample, which were recaptured in the 3\(^{rd} \) sample) and four individuals to \( n_2 \) and \( R_2 \) (total number caught and released in the 2\(^{nd} \) sample). Variable \( z_2 \) is not affected by the missing survey effort during the second sampling period because the individuals marked in that area were not similar during the first and last sampling period. Conclusively, this maximum bias holds only if the following assumptions are true: None of the two individuals marked during the first sampling period would be recaptured if the ‘missed’ area was surveyed during the second sampling period. Four individuals would be marked during the second sampling period so that \( r_{2\text{bias}} = r_2 + 3 \), \( n_{2\text{bias}} = n_2 + 4 \) and \( R_{2\text{bias}} = R_2 + 4 \).

RESULTS

Estimates of abundance based on photo-identification mark-recapture analysis

During the entire study period from February 1999 until August 2002, a total of 2074 photographs were made during 83 days of which 1499 (partially) portrayed dolphins and 558 (27\%) failed, showing merely circles in the water (Table 1). Of the dolphin photographs, 753 photographs (50\%) were selected for photo-identification because of good image quality. Some 728 photographs showed identifiable features on dorsal fins, sometimes in combination with other characteristic traits on the dolphins’ bodies, producing an average of almost 9 identifiable dorsal fin photographs per day. An additional number of 25 photographs only showed identifiable features on the dolphins’ bodies. As such, a total of 59 individual dolphins were catalogued based on dorsal fin identification. Four individuals are shown in Plate 1. Within the four initially chosen sampling periods for the Jolly-Seber method, animals appeared to differ significantly in capture-probabilities (\( G = 10.06; \text{d.f.} = 2; P < 0.01 \)), meaning that the underlying assumptions (see discussion) of the method were violated. The bias was consequently rendered insignificant by only using sampling periods, which include a high proportion (i.e. over 50\%) of the population. Therefore, sampling period October 1999 was removed from analysis, which included only 31\% of the Petersen population estimate. Another \( G \)-test for the remaining periods revealed that this time no assumptions were violated (\( G = 1.8; \text{d.f.} = 1; P = 0.17 \)). The number of dolphins identified on photograph for each sampling period (\( n_i \)) are presented in Table 1. For both Petersen method applies that the number of dolphins that were identified in the first period (May/June 2000) and recaptured on photograph during the second period (\( m_2 \) (August 2001) is 22 individuals.
Table 1. Photo-identification success rate and discovery rate of new individuals.

<table>
<thead>
<tr>
<th>Year</th>
<th>Survey period</th>
<th>Survey area coverage</th>
<th>No. dolphin photographs</th>
<th>No. identified dorsal fins</th>
<th>No. different individuals (n)</th>
<th>No. of new individuals</th>
</tr>
</thead>
<tbody>
<tr>
<td>1999</td>
<td>Fe/ Ma</td>
<td>E</td>
<td>25</td>
<td>3</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Ap/ May</td>
<td>E</td>
<td>25</td>
<td>7</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>Oc</td>
<td>E</td>
<td>49</td>
<td>28</td>
<td>16</td>
<td>13</td>
</tr>
<tr>
<td>2000</td>
<td>May/ Jun</td>
<td>E</td>
<td>206</td>
<td>90</td>
<td>33</td>
<td>21</td>
</tr>
<tr>
<td></td>
<td>Au</td>
<td>I</td>
<td>157</td>
<td>83</td>
<td>24</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>Nov</td>
<td>I</td>
<td>65</td>
<td>23</td>
<td>16</td>
<td>1</td>
</tr>
<tr>
<td>2001</td>
<td>Ja/ Fe</td>
<td>E</td>
<td>175</td>
<td>82</td>
<td>29</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>Jun/ Jul</td>
<td>I</td>
<td>267</td>
<td>127</td>
<td>37</td>
<td>1</td>
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<tr>
<td></td>
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<td>178</td>
<td>90</td>
<td>34</td>
<td>3</td>
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<tr>
<td></td>
<td>Oc/ No</td>
<td>I</td>
<td>89</td>
<td>36</td>
<td>23</td>
<td>1</td>
</tr>
<tr>
<td>2002</td>
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<td>102</td>
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<tr>
<td></td>
<td>Au</td>
<td>I</td>
<td>82</td>
<td>54</td>
<td>23</td>
<td>1</td>
</tr>
<tr>
<td>Total</td>
<td>12 periods</td>
<td></td>
<td>1499</td>
<td>728</td>
<td>59</td>
<td></td>
</tr>
</tbody>
</table>

E = Extensive monitoring survey in entire dolphin distribution area; I = Intensive monitoring survey in high dolphin density areas.

For Jolly-Seber method applies that $m_2$ is 14 individuals (using periods May/ June 2000 and January/ February 2001). The estimated re-sight probabilities for Petersen method are 65% and 67% and for Jolly-Seber method is 66%. The number of dolphins that were re-captured on photograph in the third sampling occasion (Jolly-
Seber) and identified during earlier occasions \( (n_3) \) is 28 individuals, illustrating the high re-sight probability over more than two sampling periods. The estimate of total population size using the Petersen two-sample mark-recapture method was 55 individual dolphins \( (95\% \text{ CL } = 44 - 76; \text{ CV } = 6\%) \). Calculating a potential maximum bias due to loss of individuals between the sample periods, lowers the estimate to 54 individuals \( (95\% \text{ CL } = 44 - 76; \text{ CV } = 10\%) \), which is 2% of the estimated population size above. During the 3.5 year study period at least 17 dolphins have died but the specific dolphin identities were not available and thus could not be traced back to the photo-identification catalogue. An estimate of population size using the Jolly-Seber method arrives at 48 individual dolphins \( (95\% \text{ CL } = 33 - 63; \text{ CV } = 15\%) \). The proportion of the population surviving from the 1\text{st} to the 2\text{nd} sampling occasion is 66\%. Reported number of dead dolphins between these two sampling periods is 2 individuals \( (4\% \text{ of } N_2) \). An estimate was also calculated including a maximum bias due to lack of survey effort during one of the sampling periods in one ‘closed’ area that is inhabited by a group of six dolphins. This corrected estimate arrives at 53 individuals \( (95\% \text{ CL } = 36 - 64; \text{ CV } = 19\%) \), which is 10% of the unbiased population size.

![Figure 2. Discovery rate of new individuals and number of identified dolphins per survey period in relation to the number of selected pictures](image)

Figure 2 shows the cumulative number of new individuals identified in different survey periods in combination with photographic success in obtaining identifiable pictures of dorsal fins for each sub-period. The cumulative curve begins to level off after the August 2001 survey period and during the next three survey periods only one
individual was added each time (Table 1). Some 95% of the individuals of the photo-identification catalogue are identified in the period March 1999 until August 2001. After that date a plateau in the number of new identifications is more or less reached, with only a yearly 5% increase of new identifications (three individuals) of the total photo-identification catalogue. With an annual birth rate of 10.5% of the total population, this yearly 5% increase in new identifications is within this birth rate range and may therefore be attributed to possible neonates. It should be noted though that these neonates can be identified only when they are over one-year of age, since they are otherwise difficult to photograph. So, the new identifications within any one year may include last year's neonates i.e., one year old calves. The plateau was not a result of low photographic effort, since the number of new individuals added to the catalogue is not correlated with the number of identifiable photographs ($r = 0.06; \text{DF} = 10$).

Some 98% of the identified dolphins were recaptured on photograph on at least two different days and 90% were recaptured during at least two different survey periods (Figs 3 and 4). Individual dolphins were recaptured on a mean number of 7.0 different survey days ($\pm \text{SD} = 4.7$) and 4.5 survey periods ($\pm \text{SD} = 2.4$). Individual dolphins were recaptured on a maximum of 21 days and 10 survey periods (Plate 2).

Plate 2. Example of a low quality photograph (small dorsal fin image), in which dolphin PM01 can still be identified over larger distances due the distinctiveness of its mark. Dolphin PM01 was photographed during 21 different survey days, on 41 pictures and photographed here on 23/8/00 (upper picture) and 2/7/01 (lower picture).
Figure. 3. The number of re-sighted individuals during a number of survey periods, e.g. 14 individuals were re-sighted during four different survey periods.

Figure. 4. The number of re-sighted dolphins on photograph and video over a maximum of 21 days, e.g. 14 and 11 dolphins were re-sighted on photograph and video respectively during a period of 2 until 3 days.
Feasibility of video-identification

Video recordings were made during seven different survey periods and 21 days. Total recording effort to get photo-identification images was 8.8 hours. Identifiable dorsal fins of surfacing dolphins were recorded on 79 video-images, from which 31 different individuals could be identified. On average, 9.0 identification images per hour and 4 images per day recording were produced. Four individuals were identified based on body marks alone. Fifty-two percent of the individuals were encountered on more than one day (mean = 2.1; ± s.d. 1.4; range = 1 – 5) (Figure 4).

DISCUSSION

Estimates of abundance based on photo-identification mark-recapture analysis

Violated assumptions and biases

Two methods for analysing mark-recapture results of photo-identified dolphins were used in this study, the Petersen two-sample method and Jolly-Seber method. The first method was found appropriate because during two of the 12 survey-periods the following required condition to obtain an estimate of total population size was met: photographic ‘trapping’ effort was equally spread over the entire dolphin distribution range, so that all animals have the same probability of being identified (assumption 2, see below). Most other survey periods involved intensive monitoring surveys in areas of high dolphin density only. Also, one area in between two rapids was not surveyed during the other extensive monitoring surveys due to bad weather conditions. The second method (Jolly-Seber) was applied because it allowed for gains and losses between the sampling periods. The disadvantages of using these methods are that they rely on underlying assumptions, which, if violated, produce serious biases of the results. For the Petersen method, these assumptions are: 1) the population is closed; 2) all animals have the same probability of being caught; 3) marking does not affect the catchability of an animal; 4) the second sample is a simple random sample; 5) animals do not lose their marks; and 6) all marks are reported on recovery. For the Jolly-Seber method, assumption 2 and 5 from Petersen are also relevant. Additional assumptions for Jolly-Seber are that: 7) every marked animal has the same probability of surviving from the ith to the (i + 1)th sample; 8) every animal caught in the ith sample has the same probability of being returned to the population; 9) all samples are instantaneous (Hammond, 1986).

The first and second assumptions are being violated in this study regarding the Petersen method and Jolly-Seber method, respectively, and the effects are discussed below. The first assumption of the Petersen method was violated as three dolphins (identity unknown) had died and four dolphins were born between the sampling periods. However, mortality is not likely to influence $m_2$ (total number caught on the
second occasion), since during each sampling period only 55-57% of total photo-identification catalogue was captured on film. A possible influence of dead dolphins on the \( m_2 \) (number of ‘marked’ animals recaptured on the second occasion) likely occurred although not unalterably, since the number of ‘recaptured’ animals is not equal (only 64-66%) to the total number of individuals caught on the first and second occasions. So, these dead dolphins of unknown identity could just as well not have been ‘marked’ on the first occasion or, if they were, had not been recaptured. Still, the three dead dolphins may possibly have produced a biased estimate and therefore a correction was calculated for this bias, which decreased the estimate at the most by two individuals. This bias only applies if we assume that these three dolphins were ‘marked’ at the first occasion and presumably would have been caught on the second occasion as well if they hadn’t died. In that case, the abundance estimate would be 54 individuals, within the confidence limits of the abundance estimate of 55 individuals as inferred in the results section. This small difference may be a result of the fact that a high proportion of the estimated population was captured during each sampling period (65-67%), since catching over 50% of the population limits biases that may arise through assumptions being violated (Sutherland, 1996).

Similar to mortality, recruitment (dolphins born in the period between the two sampling periods) is not likely to influence the overall number of dolphins caught on the second occasion \( n_2 \). Furthermore, neonates will not influence the number of ‘marked’ animals found on the second occasion \( m_2 \), since they were born after the first sampling period and were thus not recorded. Neonates and calves have a low chance of being identified at all since they surface very irregularly and briefly during the first few months and are hard to photograph as they swim very close to the mother. Consequently, neonates encountered in the first sampling period will most certainly not have been ‘marked’ and will for that reason also not affect one of the variables of the Petersen formula.

Violations of the second assumption due to heterogeneity between dolphins in catchability and trap responses were tested with a goodness-of-fit-test for three sampling periods used within both analysis methods and this revealed that there was no difference in capture probabilities except for the neonates and calves for which a correction factor is applied to calculate abundance estimate (see analysis). This is in contrast to most other cetacean photo-identification studies in which unequal capture probabilities are often the case due to variation in individual behaviour, such as wariness of boats or fluking behaviour, that affect the probability of obtaining good photographs (Whitehead, et al., 2000). Capture probabilities are more likely to vary for bow-riding dolphins, whereas the dolphins in this study were all photographed from some distance of the boat. Thus, boat-shyness or attraction did not play as much of a role. Since photo-identification is in principal a non-invasive technique, any issues of trap responses are not relevant here. In spite of the fact that dolphins in principal had an equal probability of being photographed, differences in distinctiveness of marks and in survey area coverage may cause capture probabilities (obtaining identifiable
Mark-recapture analysis of photo-identified Irrawaddy dolphins in the Mahakam images) to vary among individuals and cause a bias of the estimate of population size (Gowans & Whitehead, 2001). Although all photographs of good image quality yielded identifiable marks, photographs of less quality (smaller images) were only identifiable for those individuals with very distinct marks (Plate 2). Other markings needed to fill a significant part of the frame for identification and therefore more slides were discarded for use in connection with these features. Another bias in capture probability was related to differences in survey area coverage for each sampling period in the calculation of the Jolly-Seber estimate. However, the G-test result and the high percentage of re-sightings over different survey days and periods (95% and 90% of total identified individuals were re-sighted over two days and periods or more, respectively), indicate that the bias is not large, possibly due to the fact that a large part of the population was caught during both samples, as stated earlier. Nevertheless a maximum bias was calculated that could affect the Jolly-Seber estimate for the difference in area coverage. This bias produced an estimate that only differed with three individuals from the Jolly-Seber estimate. Finally, dolphins in this study were only identified using natural marks, which would be stable over long sampling intervals (such as notches, cuts, scars and fin shapes) to prevent biases when marks are lost (such as pigmentation patterns) as suggested by Gowans & Whitehead (2001). Furthermore, other underlying assumptions of both methods did not seem problematic in this study.

The difference between the total number of identified dolphins (59) and the estimated total population size ($N = 48-55$), may be explained by the fact that the first number was derived over a 3.5 year study period, during which 17 dolphins had died. The total number identified dolphins does therefore not represent an abundance estimate.

The proportion of the population surviving from the 1st to the 2nd sampling occasion (66%) based on the Jolly-Seber equation whereas the proportion surviving based on the reported number of dead dolphins between these two sampling periods is 96%. The difference may be explained in the fact that the probability of survival within Jolly-Seber is determined by sampling the marked population only and variation in the size of the marked population may occur between two sampling periods for reasons other than mortality and emigration. For example, photographs are not always successful for all sightings within each sampling period due to the dolphins’ group behaviour at that specific moment, which may vary through time for the same group. In this way, some groups may be missed from identification during one period but identified during another period.

Identifiability

As stated above, in this study, from all photographs of good image quality of dorsal fins, individual dolphins could be identified. This agrees with a photo-identification study on coastal Irrawaddy dolphins in North Queensland, Australia, although juveniles were reported to lack any distinctive features to allow for identification (Parra and Corkeron, 2001). Of Pacific white-sided dolphins, *Lagenorhynchus obliquidens*
and Indo-Pacific humpbacked dolphins, *Sousa chinensis*, only a percentage of dolphin dorsal fins could be identified (Jefferson and Leatherwood, 1997; Morton, 2000). In addition, as in the Australian study, no standardized identification measure could be used such as the Dorsal Fin Ratio (Defran *et al.*, 1990) to identify Irrawaddy dolphins in the Mahakam, since fins lacked clearly distinct top and bottom points. In contrast to the studies mentioned above on other species than *Orcaella brevirostris*, Irrawaddy dolphins in this study and others could also be identified based on the variation of dorsal fin shapes (Stacey, 1996; Parra and Corkeron, 2001). With regard to possible false matches: I only found three dolphins with more uniform, smooth dorsal fin shapes (although not similar compared to each other). However, each of these dolphins were only re-sighted on 5, 7 and 11 different survey days, which is within the standard deviation of the mean number of days on which all dolphins were re-sighted (mean = 7 days, SD = 4.7). So, the chance seems small that different dolphins were identified as one of these three dolphins. Then I would expect the number of sighting days for these dolphins to be much more numerous. Also, I found these fins still identifiable on basis of overall shape, even though characteristic notches were missing.

With regard to identification of calves and juveniles, I found that Irrawaddy dolphins in the Mahakam River did have identifiable features on their dorsal fins. This stands in contrast to Parra and Corkeron (2001), who conducted a photo-identification study of coastal Irrawaddy dolphins in Australia and found that calves and juveniles did not have any distinctive features to allow identification. During each of the extensive sampling periods (covering entire dolphin distribution range), we encountered one group of animals consisting of some six juveniles without adults. Unfortunately, individuals of these groups were never successfully photographed, because of their elusive surfacing-behaviour. Only drawings of dorsal fins, (made by aid of binoculars) and one photograph with distinctive marks on the juvenile’s body were available for these. Juveniles in mixed groups were on the other hand much less shy, in fact they often surfaced near the boat. Since no record was kept in the field of the dolphin age classes of each photograph, it is not possible to trace which identified dolphin is a juvenile and which is an adult on basis of the picture alone. However, occasionally, when drawings were made during the study of several characteristic dorsal fins, age class was also noted and these included both juveniles and calves.

The high percentage of individuals that were re-sighted on more than one occasion (98% of 59 identified dolphins) is an indication of the closeness of the Mahakam dolphin population. Percentage of re-sightings were similar (97% and 100%) for resident populations of marine tucuxis, *Sotalia fluviatilis* in Southern Brasil and of 21 identified bottlenose dolphins, *Tursiops truncatus*, in the Stono River estuary in South Carolina (Flores, 1999; Zolman, 2002). Resightings of seasonally occurring groups are typically lower; varying percentages of 32%, 50% and 57% were found of 675 identified individual Pacific white-sided dolphins, *Lagenorhynchus obliquidens*, in the Broughton Archipelago, Canada, 35 identified Irrawaddy dolphins, *Orcaella brevirostris*, in Cleveland and Bowling Green Bay in North Queensland, Australia and 213
identified Indo-Pacific humpbacked dolphins, *Sousa chinensis*, in Hong Kong waters, respectively (Morton, 2000; Parra, 2001; Jefferson, 2000).

**Comparison of different techniques to estimate population abundance**

The estimates of population size based on two different methods in this mark-recapture study are very much in agreement with each other since both estimates are within the confidence limits of each other (combined between 33 and 76). It may be noted though that the Petersen estimate \(N = 55\) is somewhat higher than the Jolly-Seber estimate \(N = 48\), whereas the coefficient of variation is smaller for the first estimate \(CV = 6\%\) and 15\%). The latter estimate is close to the estimate derived from direct counts and strip-transects in May/June 2000 \(N_{\text{count}} = 35\) and \(N_{\text{strip}} = 43\) (Kreb, 2002) with both estimates within the confidence limits of the Jolly-Seber estimate. Because the low estimates calculated here represent the total population size of dolphins in the Mahakam, immediate conservation measures are required to reduce the high minimum mortality rate of 10.5\% dolphins of total population per year. Moreover, intended live-captures of dolphins for display in a local oceanarium to be built in the district’s capital city along the Mahakam should therefore definitely not be allowed for this small population.

In order to monitor future trends in abundance, photo-identification may be a valuable tool. However, to increase precision and prevent biases due to gains and losses of individuals I recommend that photographs be taken during two extensive monitoring surveys in sequence covering the entire dolphin distribution range with a minimum time interval. Conclusively, since the results of the mark-recapture studies and direct count and strip-transect studies are very similar, future surveys to monitor trends in abundance of the latter type are feasible, if one needs to be cost efficient. However, surveys in combination with photo-identification are preferable in order to obtain data on long-term social system and migration patterns.

**Feasibility of video-identification**

The number of identifiable video-images per hour recording in this study (9 images/hr), was much lower than those recorded in the video-identification study of bottlenose dolphins in South Carolina (Zolman, 2002), which yielded 31 images per hour recording time. This may be a result of the fact that in the latter study only a video was used for identification of dolphins, which may increase the efficacy to make good quality recordings. Another reason is that it may be more difficult to record dorsal fins of Irrawaddy dolphins because of their shy and irregular surfacing pattern (Kreb, 1999). Also, the number of identifiable video images per day were much lower i.e., four identifiable video images per day, in comparison to the still photography in this study, which produced nine identifiable photographs per day. Nevertheless, although the yield of identifiable images may be less than in other studies and in
comparison to still photography, video-identification used as an additional tool has some advantages. First, in most cases the entire movement of the dolphin is visible, during play-back including all the different angles from which a dorsal fin can be seen. This was particularly useful in cases when there were any doubts within the photo-identification catalogue about whether two assumedly different identified dorsal fins belong in fact to one and the same individual. Although dorsal fin pictures were always attempted to be taken perpendicularly to the dolphins body axis close to the dorsal fin region, small deviations from this angle could in some cases cause confusion about the identification. Second, this technique can link body characteristics to individuals, which are initially identified based on dorsal fins alone. Third, for other purposes, such as study of social structure, video-recordings make it possible to record the physical position of individual dolphins with regard to each other.

However, disadvantages of the use of a video camera were experienced by author and field-assistants in connection with the slow adjustment between wide-angle and zoom modes. Even though we tried to use a fixed zoom length and estimated where the dolphins would surface, the manoeuvrability of the video camera suffered in comparison with the photo-camera. In addition, the quality of video images for which a digital zoom was used often did not allow for accurate identification. Since the images were analysed by using the slow motion, or pause mode the quality of still video images decreased significantly as a consequence, as did images recorded with the optical zoom.

No mark-recapture analyses were performed using video images, since the images were not recorded systematically throughout the study period. The quality of the still video images was found low in comparison to the photographs. Therefore, identifications were not directly based on the video images but were first traced back to the photo-identification catalogue. However, my overall conclusion is that video-identification in combination with photo-identification appeared to be useful for determining identities of individual dolphins.

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