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# Population sizes, site fidelity and residence patterns of Australian snubfin and Indo-Pacific humpback dolphins: Implications for conservation

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## ABSTRACT

Very little is known about the ecology of snubfin *Orcaella heinsohni* and Indo-Pacific humpback dolphins *Sousa chinensis* in Australian waters. We used photo-identification data collected between 1999 and 2002 in Cleveland Bay, northeast Queensland, to estimate abundance, site fidelity and residence patterns of these species in order to make recommendations for their effective conservation and management. Our abundance estimates indicate that less than a hundred individuals of each species inhabit this coastal area. Even with relatively unbiased and precise abundance estimates population trends will be extremely difficult to detect in less than three years unless changes in population size are very high (>20% p.a.). Though both species are not permanent residents in Cleveland Bay, they both used the area regularly from year to year following a model of emigration and reimmigration. Individuals of both species spend periods of days to a month or more in coastal waters of Cleveland Bay before leaving, and periods of over a month outside the study area before entering the bay again. Because of their small population sizes and movement patterns, snubfin and humpback dolphins are particularly vulnerable to local extinction. Our results illustrate that: (1) detection of population trends should not be a necessary criterion for enacting conservation measures of both species in this region, and (2) efforts to maintain viable populations of both species in Cleveland Bay must include management strategies that integrate anthropogenic activities in surrounding areas.

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## 1. Introduction

Coastal areas are among the marine habitats most at risk from human activities (McIntyre, 1999; Moore, 1999). Consequently, coastal dolphins are among the most threatened species of cetaceans and most in need of management intervention to reduce anthropogenic threats (Thompson et al., 2000; DeMaster et al., 2001). Estimates of population size

and movement patterns are integral components of the information needed to manage human impacts on wild cetaceans (Hooker et al., 1999; Wilson et al., 1999; Ingram and Rogan, 2002; Hastie et al., 2003).

The conservation status of snubfin dolphins *Orcaella heinsohni*, formerly known as Irrawaddy dolphins *Orcaella brevirostris* and Indo-Pacific humpback dolphins *Sousa chinensis* (hereafter humpback dolphins) in Australian waters is

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unknown, largely because of lack of research on either species (Corkeron et al., 1997; Parra et al., 2002, 2004). This deficiency hampers conservation and management efforts and our ability to assess the impact of human activities on local populations of this species. In addition, the latest efforts to resolve the taxonomy of the members of the genera *Orcaella* indicate that snubfin dolphins are endemic to the Australian/Papua New Guinea region (Beasley et al., 2005). Likewise, species-level taxonomy of the genus *Sousa* remains in dispute (Jefferson and Karczmarski, 2001; Jefferson, 2004). As both species may potentially be endemic to Australian waters, their conservation value is high and the estimation of most basic population parameters (e.g., population size) is particularly significant and urgent.

Obtaining accurate and precise estimates of the abundance of cetaceans is usually difficult, expensive and time consuming (Gerrodette, 1987; Taylor and Gerrodette, 1993). Sampling and environmental variability affect our ability to accurately estimate cetacean populations sizes and trends (Taylor and Gerrodette, 1993; Forney, 2000; Thompson et al., 2000). However, relatively precise and unbiased estimates of population size can result from careful survey design and consideration of the assumptions inherent in estimation methods (Wilson et al., 1999; Read et al., 2003). Additionally, power analysis can quantify the ability of monitoring programs to detect population trends (Gerrodette, 1987; Taylor and Gerrodette, 1993).

Studying the movement patterns of cetaceans is also difficult, mainly because they spend most of their lives in an underwater environment. Detailed studies of marine mammal movements generally depend on remote tracking (Martin and DaSilva, 1998; Kochman et al., 2003; Austin et al., 2004).

However, opportunistic identification of individual animals provides data that can be used to produce realistic movement models (Whitehead, 2001). Snubfin and humpback dolphins are reliably identified from marks and pigmentation patterns on their dorsal fins (Corkeron, 1990; Parra and Corkeron, 2001), making this technique appropriate for the study of their movement patterns.

Here we present data on population sizes, site fidelity and residence patterns of snubfin and humpback dolphins in coastal waters of Cleveland Bay, adjacent to the city of Townsville in the Great Barrier Reef World Heritage Area, northeast Queensland, Australia. Our purpose is to inform and improve the design of conservation and management interventions towards these species in Australian waters.

## 2. Methods

### 2.1. Data collection

Boat-based surveys were conducted in the coastal waters of Cleveland Bay Dugong Protected Area (hereafter Cleveland Bay, Fig. 1) from January 1999 to October 2002. The study area extended 5–6 km offshore covering an approximate area of 310 km<sup>2</sup> from Cape Cleveland to Black River mouth (Fig. 1). Surveys were conducted at a steady speed of 10–12 km/h from a 4.7 m rigid-hulled inflatable boat, powered by a 50-hp outboard engine. Three observers searched for dolphins (one on each side of the boat and one ahead) with naked eye and 7 × 50 binoculars. All surveys were conducted in calm sea conditions (i.e., Beaufort sea state ≤ 3 and swell ≤ 1 m) between 0600 and 1400 h. For survey purposes, the study area was divided into four sections (A–D) of similar lengths (Fig. 1).

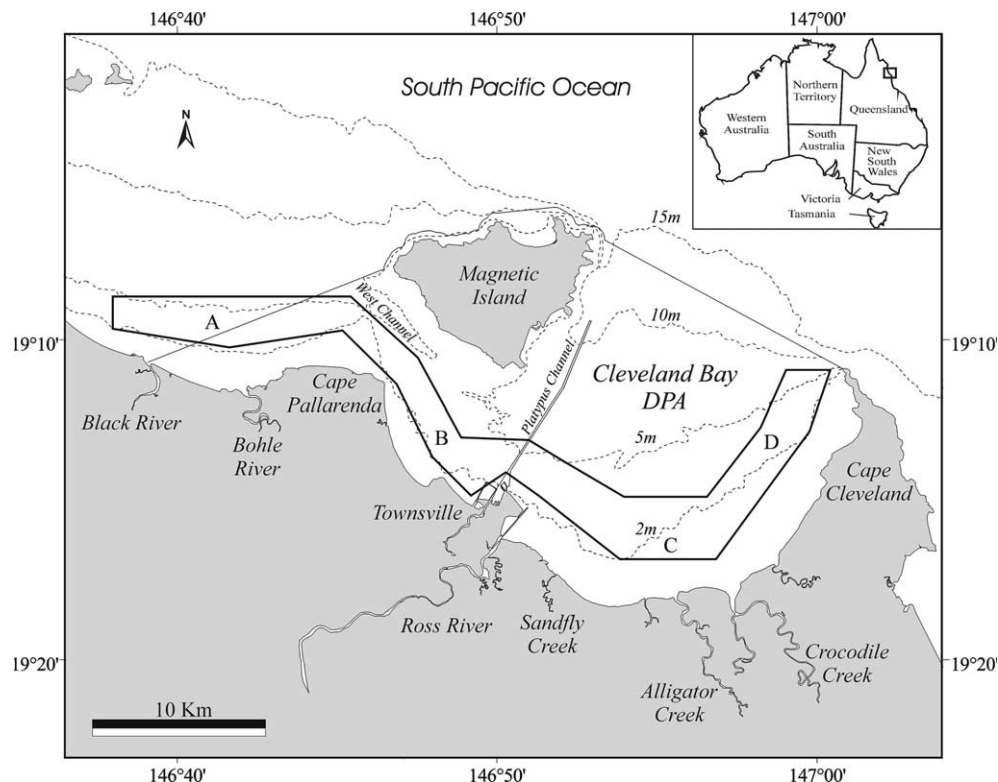


Fig. 1 – Map of Cleveland Bay Dugong Protected Area (DPA) indicating survey route (—) and limits of DPA (---).

Surveys followed a predetermined route from Townsville Harbour to Black River mouth (covering sections A and B) or to Cape Cleveland and back (covering sections C and D).

We defined a school as dolphins with relatively close spatial cohesion (i.e., each member within 100 m of any other member) that were involved in similar (often the same) behavioural activities (modified from Connor et al., 1998). Once a dolphin school was sighted, it was approached slowly, to within 10 m, to record its location, identify the species, estimate school size, assess the age composition of the school, and take photographs of individual animals for photo-identification. To define the age composition of a school, three age classes were distinguished based on behavioural cues and visual assessment using the average adult size for each species as a reference: (1) adults: individuals about 2–3 m long; (2) juveniles: individuals approximately 2/3 the length of an adult, usually swimming in association with an adult, but sometimes swimming independently; (3) calves: individuals with light brown (snubfin dolphins) or light grey (humpback dolphins) skin colour,  $\leq 1/2$  the length of an adult, in close association with an adult, and swimming regularly besides or slightly behind an adult.

Photographs of individuals were taken as perpendicular to the dolphin's body axis as possible and concentrated mainly on the dorsal fin. All photographs taken on surveys were examined and classified into three grades (excellent, good, and poor) according to focus, contrast between dorsal fin and background, relative angle to the animal, and the size of dorsal fin relative to the frame. Photographs classified as excellent and good were used to identify individuals and de-

velop identification catalogues for each species (Würsig and Jefferson, 1990).

### 2.2. Data selection

Most fieldwork effort took place during the dry season (May–Nov). Nearly all identified dolphins of both species (snubfin: 98%; humpback: 94%) were captured during these months (Fig. 2), thus our analysis of capture–recapture data was limited to this season. To obtain adequate sample sizes, capture histories of each individual dolphin were pooled by year (i.e., if an animal was photographed at least once during May–Nov it was considered captured for that year), resulting in four sampling occasions (1999, 2000, 2001, and 2002).

### 2.3. Estimating population size

We defined the term 'population' for both snubfin and humpback dolphins as the number of individuals of each species frequenting the study area (Begon et al., 1996; Williams et al., 2002) and used the terms abundance and population size synonymously. Population sizes of snubfin and humpback dolphins were estimated using Schwarz and Arnason's parameterization of the Jolly-Seber open population model (Schwarz and Arnason, 1996). This model provides abundance estimates while allowing entries (i.e., births, immigration) and losses (i.e., death, permanent emigration) in the population under study and is suitable for long-term studies where the use of models assuming population closure is not reasonable.

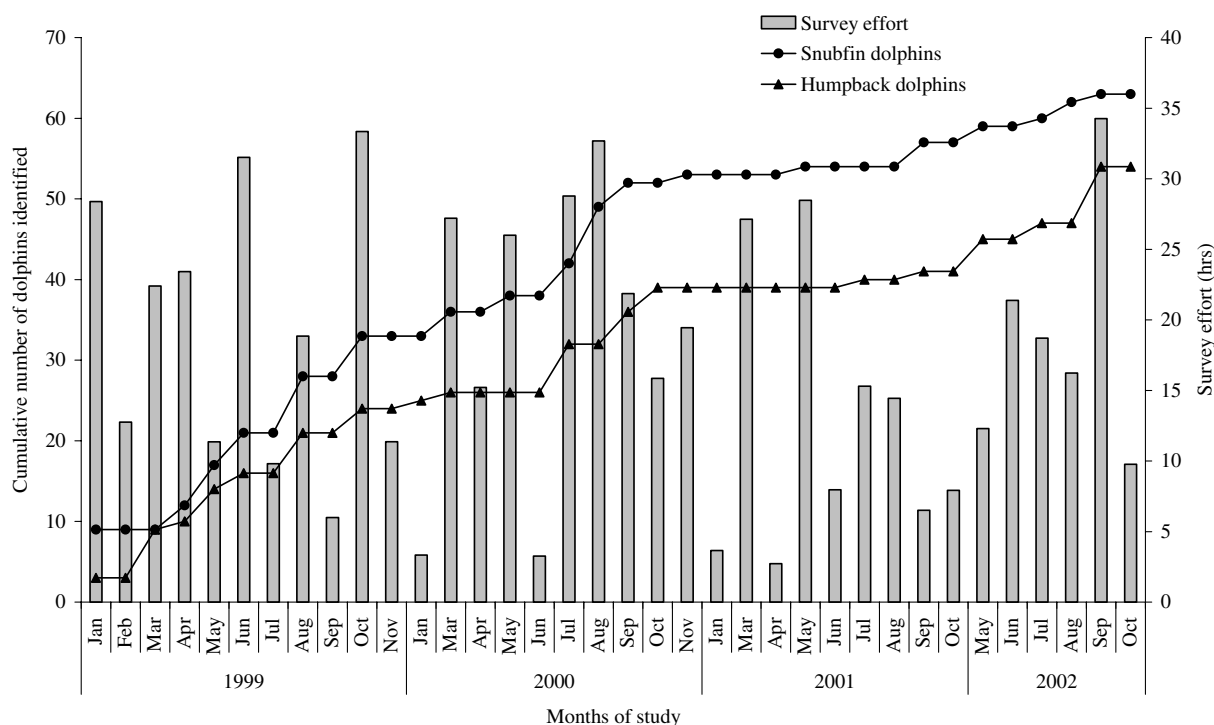


Fig. 2 – Discovery curves of the cumulative number of snubfin and humpback dolphins identified between January 1999 and October 2002 in Cleveland Bay. The bars represent the number of survey hours spent in the field during each month of study.

**Table 1 – Abundance estimates of (a) snubfin and (b) humpback dolphins in Cleveland Bay between January 1999 and October 2002**

Jolly-Seber models <sup>a</sup>	Marked animals							Total population					Model selection			
	Year	n	p	SE	N	SE	CV	95% CI	$\theta$	$N_{\text{total}}^b$	SE	CV	95% CI	np	AIC <sub>c</sub>	$\Delta\text{AIC}_c$
<b>(a) Snubfin dolphins</b>																
<i>(<math>\phi_t, p_t</math>)</i>	1999	32	na	na	na	na	na	na	0.78	na	na	na	na	8	171.8	1.9
	2000	43	0.9	0.07	48	4.5	0.09	40–58	0.70	69	7.0	0.10	57–84			
	2001	28	0.6	0.10	45	6.1	0.14	35–59	0.67	68	9.5	0.14	51–89			
	2002	32	na	na	na	na	na	na	0.63	na	na	na	na			
<i>(<math>\phi_t, p_*</math>)</i>	1999	32	0.7	0.06	na	na	na	na	0.78	na	na	na	na	7	174.3	4.4
	2000	43			54	4.5	0.08	46–64	0.70	78	7.1	0.09	65–93			
	2001	28			42	5.0	0.12	33–53	0.67	62	7.8	0.13	49–80			
	2002	32			43	6.5	0.15	32–58	0.63	69	10.9	0.16	51–94			
<i>(<math>\phi_*, p_t</math>)</i>	1999	32	na	na	na	na	na	na	0.78	na	na	na	na	7	169.9	0.0
	2000	43	0.9	0.07	49	4.3	0.09	41–58	0.70	70	6.7	0.10	58–84			
	2001	28	0.6	0.09	44	5.4	0.12	35–56	0.67	66	8.5	0.13	52–85			
	2002	32	0.8	0.13	43	7.2	0.17	31–59	0.63	68	11.9	0.17	48–95			
<i>(<math>\phi_*, p_*</math>)</i>	1999	32	0.7	0.06	na	na	na	na	0.78	na	na	na	na	5	170.8	0.9
	2000	43			53	3.6	0.07	46–60	0.70	76	6.0	0.08	65–88			
	2001	28			43	4.6	0.11	35–53	0.67	64	7.4	0.11	51–80			
	2002	32			42	5.6	0.13	32–54	0.63	67	9.4	0.14	51–88			
<b>(b) Humpback dolphins</b>																
<i>(<math>\phi_t, p_t</math>)</i>	1999	20	na	na	na	na	na	na	0.77	na	na	na	na	8	155.9	1.8
	2000	25	0.8	0.13	32	5.9	0.18	23–46	0.66	49	9.1	0.19	34–70			
	2001	13	0.5	0.13	26	6.1	0.23	17–41	0.79	34	7.8	0.23	21–53			
	2002	30	na	na	na	na	na	na	0.77	na	na	na	na			
<i>(<math>\phi_t, p_*</math>)</i>	1999	20	0.7	0.08	na	na	na	na	0.77	na	na	na	na	7	156.8	2.6
	2000	25			35	5.3	0.15	26–47	0.66	53	8.4	0.16	39–72			
	2001	13			24	4.9	0.20	16–35	0.79	30	6.2	0.21	20–45			
	2002	30			45	6.5	0.14	34–60	0.77	59	8.7	0.15	44–78			
<i>(<math>\phi_*, p_t</math>)</i>	1999	20	0.7	0.10	na	na	na	na	0.77	na	na	na	na	7	154.1	0.0
	2000	25	0.7	0.10	34	4.1	0.12	27–43	0.66	51	6.6	0.13	40–66			
	2001	13	0.5	0.13	25	5.2	0.21	17–38	0.79	32	6.7	0.21	21–48			
	2002	30	0.8	0.23	35	9.3	0.27	21–59	0.77	46	12.2	0.27	27–77			
<i>(<math>\phi_*, p_*</math>)</i>	1999	20	0.7	0.09	na	na	na	na	0.77	na	na	na	na	5	155.1	1.0
	2000	25			34	4.5	0.13	27–44	0.66	52	7.1	0.14	40–68			
	2001	13			27	4.9	0.18	19–38	0.79	34	6.3	0.19	24–49			
	2002	30			42	7.3	0.18	30–59	0.77	54	9.6	0.18	38–77			

The model that best fitted the data of both species according to the Akaike Information Criterion corrected for small sample sizes (AIC<sub>c</sub>) was model ( *$\phi_*, p_t$* ). Models ( *$\phi_t, p_t$* ) and ( *$\phi_*, p_*$* ) also provided good fit to the data (i.e.,  $\Delta\text{AIC}_c$  scores within 2 units of best model) of both species. Following the parsimony principle, the model ( *$\phi_*, p_*$* ) was selected as the most appropriate (in bold italics) because it has fewest parameters. A Model notation follows Lebreton et al. (1992):  $\phi$  = survival probability;  $p$  = capture probability;  $t$  = time dependent effect; and  $*$  = constant effect. Other notations:  $n$  = number of animals captured;  $p$  = capture probability;  $N$  = estimate of number of marked animals; SE = standard error; CV = coefficient of variation; CI = confidence interval;  $\theta$  = proportion of identifiable animals;  $N_{\text{total}}$  = estimate of total population size after correcting for proportion of identifiable individuals; np = number of estimable parameters in model;  $\Delta\text{AIC}_c$  = difference between AIC<sub>c</sub> and minimum AIC<sub>c</sub> obtained; and na = not available.

b The total population size ( $N_{\text{total}}$ ) of snubfin and humpback dolphins in Cleveland Bay and its variance ( $\text{Var}(N_{\text{total}})$ ) were derived as (Williams et al., 1993; Wilson et al., 1999; Chilvers and Corkeron, 2003):

$$N_{\text{total}} = \frac{N}{\theta}, \quad \text{Var}(N_{\text{total}}) = N_{\text{total}}^2 \left( \frac{\text{var}N}{N^2} + \frac{1-\theta}{n\theta} \right).$$

Four conditional forms of the Jolly-Seber model were fitted to the data (Table 1). The parameters of each model were estimated using maximum likelihood estimation using the computer program POPAN-5 (Schwarz and Arnason, 1996; Arnason et al., 1998). The appropriate model for inference was selected using the Akaike Information Criterion corrected for small-sample sizes (AIC<sub>c</sub>) (Burnham and Ander-

son, 1998). Models differing by less than two units from the model with minimum AIC<sub>c</sub> ( $\Delta\text{AIC}_c$ ) also provide good descriptions of the data (Burnham and Anderson, 1998). When more than one model provided a good description of the data, we followed the principle of parsimony and selected the model with lower number of parameters as the most appropriate.

### 2.4. Total population size

Our abundance estimates from Jolly-Seber models pertain only to the population of marked animals. The total population size (and its variance) of snubfin and humpback dolphins in Cleveland Bay were estimated by taking into account the proportion of identifiable individuals of each species (Williams et al., 1993; Wilson et al., 1999; Chilvers and Corkeron, 2003). The proportion of identifiable individuals within the population for each year was estimated as the number of excellent and good quality photographs showing a recognisable individual from a random sample of 300 photographs from each species.

### 2.5. Validation of model assumptions

The estimation of demographic parameters under Jolly-Seber capture–recapture models requires several assumptions; the violation of which can lead to bias in population estimates (Table 2). We used information on the biology of these two

species and goodness-of-fit tests to evaluate potential violations of population analyses. We considered all assumptions to be valid (Table 2).

### 2.6. Analysing the power to detect population trends

We used Gerrodette's (1987) inequality model to investigate the ability of a series of population estimates to detect population trends. The probability of Type I and II errors was 0.05 as this is the standard level of  $\alpha$  and  $\beta$  used to claim a statistically significant effect, and high statistical power (Power =  $1 - \beta = 0.95$ ). We used the range of CV values obtained from the population estimates to investigate the time it will take to detect different rates of population change by conducting annual surveys.

### 2.7. Site fidelity

Although some animals were identified more than once during the same day, the first sighting of the day, and only

**Table 2 – Validation of the assumptions involved in Jolly-Seber capture–recapture models used for the estimation of population sizes of snubfin and humpback dolphins in Cleveland Bay**

Assumption	Bias in estimates	Validation <sup>a</sup>	References
Mark recognition and mark loss	Upwards	<ol style="list-style-type: none"> <li>(1) Used only good and excellent quality photographs to identify individuals.</li> <li>(2) Analysis restricted to individuals with long-lasting marks.</li> <li>(3) Regular sampling over four years permitted comprehensive monitoring of marked animals.</li> <li>(4) Additional marks (i.e., white pigmentation patterns, dorsal fin shape) to notches and scars in dorsal fin were also considered for individual identification.</li> <li>(5) Only one experienced person was responsible for cataloguing photographs ensuring consistency in the recognition of individuals and grading of photographs.</li> </ol>	Pollock et al. (1990), Williams et al. (2002)
Homogeneous capture and survival probabilities	Downwards	<ol style="list-style-type: none"> <li>(1) The pooled <math>\chi^2</math> statistics (Test 2 + Test 3) indicated that the assumptions of homogeneous capture and survival probabilities were not violated (snubfin dolphins: <math>\chi^2 = 7.0</math>; <math>df = 4</math>; <math>p = 0.135</math>; humpback dolphins: <math>\chi^2 = 7.94</math>; <math>df = 4</math>; <math>p = 0.094</math>).</li> <li>(2) Average capture probabilities obtained in this study for both species were relatively high (&gt;0.5, see Table 1).</li> </ol>	Burnham et al. (1987), Pollock et al. (1990), Williams et al. (2002)
No behavioural responses	Trap shy = upwards Trap happy = downwards	<ol style="list-style-type: none"> <li>(1) With photo-identification techniques animals are not subject to stress induced by capture, handling, or physical marking by the researcher.</li> <li>(2) Pradel's test for trap-dependence showed no indication of "trap-happy" or "trap-shy" behaviour by marked individuals (snubfin dolphins: <math>Z = 0.0</math>; <math>df = 4</math>; <math>p = 1</math>; humpback dolphins: <math>Z = 0.67</math>; <math>df = 4</math>; <math>p = 0.497</math>).</li> </ol>	Pollock et al. (1990), Pradel (1993), Williams et al. (2002)
Permanent emigration	Direction of bias depends on the nature of the emigration process	<ol style="list-style-type: none"> <li>(1) Estimates of the capture probabilities of both species were relatively high (see Table 1).</li> <li>(2) No indication of heterogeneity in capture probabilities (see pooled <math>\chi^2</math> statistics of Test 2 + Test 3 above).</li> </ol>	Kendall (1997), Williams et al. (2002)
Instantaneous sampling	Upwards	Sampling occasions selected for analysis were relatively short in duration (6–7 months) in comparison with the dolphins' lifespan (decades).	Pollock et al. (1990), Williams et al. (2002)

<sup>a</sup> The pooled  $\chi^2$  statistics (Test 2 + Test 3) for homogeneity in capture and survival probabilities and Pradel's test for trap-dependence were carried out using the program U-Care (Choquet et al., 2002).

sightings separated at least a day apart were used in the analysis of site fidelity and residence patterns to minimise likelihood of dependence in the data. To investigate the presence of identified individuals in the study area over time, we calculated: (1) the number of months a dolphin was identified as a proportion of the total number of months in which at least one survey was conducted (i.e., monthly sighting rate) and (2) the number of calendar years a dolphin was identified as a proportion of the total surveyed (i.e., yearly sighting rate). Potentially, monthly sighting rates range between 0.02 (i.e., animals sighted in only one month out of 36) and one for an individual sighted in all months. Similarly, potential yearly sighting rates ranged from 0.25 (i.e., animals sighted in only one year out of four) and one for an individual sighted in all four years of study.

We used the CrimeStat spatial statistics software to measure the standard distance deviation ( $S_{XY}$ ) to investigate if individual dolphins displayed site fidelity towards specific areas within Cleveland Bay. The standard distance deviation is the spatial equivalent to the standard deviation (Levine, 2002). The  $S_{XY}$  measures the standard deviation of the distance of the location of each individual from their mean centre:

$$S_{XY} = \sqrt{\frac{\sum (X_i - \bar{X})^2 + \sum (Y_i - \bar{Y})^2}{N - 2}}$$

where  $X_i$  and  $Y_i$  are the coordinates of the location of each individual dolphin (in metres),  $\bar{X}$  and  $\bar{Y}$  are the means of each coordinate and  $N$  is the total number of times an individual animal was sighted. The more dispersed individual locations are, the larger the standard distance deviation and the less faithful an individual was to a specific area within Cleveland Bay. To provide a balance between the representativeness of the data (i.e., include the maximum number of individuals) and its reliability (e.g., include individuals with maximum sighting frequencies, Chilvers and Corkeron, 2002),  $S_{XY}$  was calculated only for individuals that were observed on at least eight occasions, separated at least one day apart and with at least one of those occasions separated by a year.

## 2.8. Residence times

To estimate the amount of time identified individuals reside inside Cleveland Bay, we calculated the probability that if an individual is identified in the study area at any time, it is identified during any single identification made in the area some time lag later (i.e., lagged identification rate, Whitehead, 2001). Plots of lagged identification rates against time were produced for all identified individual dolphins of each species as these plots provided indications of the temporal use of the area by individual animals. A plot of lagged identification rates that drops sharply after a certain time lag and then levels off above zero after a larger time lag indicates that: (1) many animals leave the study area after residing in the area for a certain time lag, (2) some animals remain resident, and/or (3) other animals reimmigrate into the study area (Whitehead, 2001).

After estimating lagged identification rates for each species, we compared the observed rates to expected lagged

identification rates from exponential mathematical models of emigration/mortality and emigration + reimmigration (Whitehead, 2001). The model minimising the adjusted Akaike Information Criterion for small-sample bias ( $AIC_c$ ) was chosen as the best fit model (Burnham and Anderson, 1998). Computation of lagged identification rates and model fitting was carried out using the computer software SOCPROG 2.1 (Whitehead, 2004).

## 3. Results

### 3.1. Photo-identification and proportion of animals identifiable

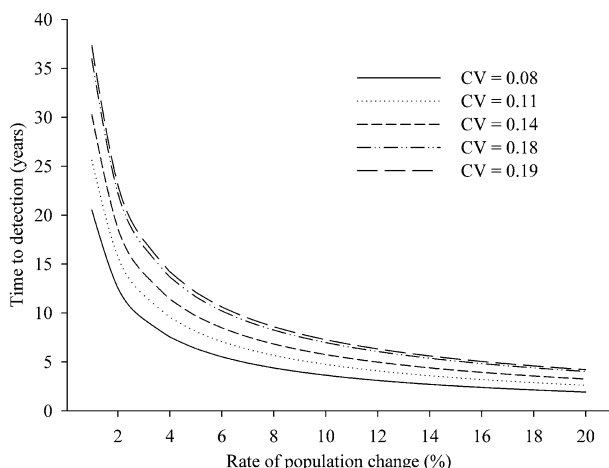
Between 1999 and 2002 a total of 117 schools of snubfin dolphins and 143 of humpback dolphins were sighted in Cleveland Bay, from which 63 snubfin and 54 humpback dolphins were identified. All identified animals were adults, with the exception of one juvenile snubfin dolphin. Overall, the cumulative number of identified individuals (i.e., rate of discovery) of both species did not decrease with time, suggesting populations were open for the duration of the study and/or unrecognisable animals acquired new marks as our study progressed (Fig. 2). We considered the latter unlikely as the new animals been added to the catalogue displayed old marks instead of fresh new marks. The rate of discovery of new individuals was not steep with an average of  $1.7 \pm 0.40$  ( $\pm$ SE) snubfin and  $1.5 \pm 0.35$  humpback dolphins added to the catalogue per month. By the end of 2000, 84% of the recognisable snubfin and 72% of humpback dolphins had been identified.

The analysis of random photographs of excellent and good quality for each year indicated that the proportion of snubfin and humpback dolphins that could be reliably identified from the population were high (Table 1). The proportion of identifiable snubfin and humpback dolphins varied from 0.63 to 0.78 and from 0.66 to 0.79, respectively, depending on the year.

### 3.2. Population size of marked animals and model selection

Abundance estimates of marked animals ( $N$ ) from the four Jolly-Seber models fitted to the data are presented in Table 1. For each year where a comparison is available, abundance estimates of marked animals for both species did not vary greatly between models. The model that best fitted the data for snubfin and humpback dolphins was the model in which capture probabilities vary with time and survival probabilities were constant ( $\phi_t, p_t$ , Table 1). The full time dependent model ( $\phi_t, p_t$ ) and the constant model ( $\phi, p$ ) also provided good fit to the data (i.e.,  $\Delta AIC_c$  scores within 2 units of best model) of both species, with similar estimates of  $N$  to the best model (Table 1).

Following the principle of parsimony, we selected as best model for both species, the constant capture-constant survival model ( $\phi, p$ ) as it has the lowest number of parameters. Estimates of  $N$  from the constant capture-constant survival model varied from 42 to 53 marked snubfin dolphins and from 27 to 41 marked humpback dolphins (Table 1).



**Fig. 3 – Relationships between different rates of population change, time until trend detection, and coefficient of variation (CV) for annual population estimates. The CVs used to present data variability are the values obtained for population estimates of snubfin and humpback dolphins. The probabilities of Type I ( $\alpha$ ) and Type II ( $\beta$ ) errors were set at 0.05.**

**3.3. Total population size**

The total number of snubfin and humpback dolphins using the study area was less than 100 individuals for each species (Table 1). The total population size for snubfin dolphins ranged from 64 individuals in 2001 to 76 in 2000 (Table 1a),

and from 34 humpback dolphins in 2001 to 54 in 2002 (Table 1b).

**3.4. Ability to detect population trends**

The time required to detect a population trend in either species by carrying annual surveys decreases with increasing rates of population change (Fig. 3). With the highest level of precision obtained for the abundance estimates of snubfin dolphins (CV = 0.08), we estimated that it will take six years to detect a population change of 5% p.a., but two years to detect a 20% p.a. change (Table 3). The total percentage change in the population of either species that will have occurred by the time a 5% or 20% p.a. increase or decrease is detected is high (Table 3). For example, a population of 76 snubfin dolphins (CV = 0.08) decreasing at 5% per year, would consist of only 55 individuals by the time such trend was detected. If the rate of decline was 20% per year, only 49 individuals would remain by the time the trend was detected. For a population of 52 humpback dolphins (CV = 0.14) estimates are 32 and 25 respectively.

**3.5. Site fidelity**

Twelve snubfin dolphins (19%) and 22 (41%) humpback dolphins were identified only once throughout the study period (Fig. 4a). However, 68% of snubfin and 52% of humpback dolphins were identified in more than one calendar year (Fig. 4b).

Relative to the total number of months surveyed, most snubfin dolphins identified were sighted relatively infrequently (mean  $\pm$  SE = 0.12  $\pm$  0.01 sightings per month) (Fig. 4c). However, yearly sighting rates (0.54  $\pm$  0.03 sightings per year)

**Table 3 – Effect of different annual rates of population change on the number of years required to detect population trends of snubfin and humpback dolphins with yearly survey intervals ( $t = 1$ ) following Gerrodette’s inequality model (1987)**

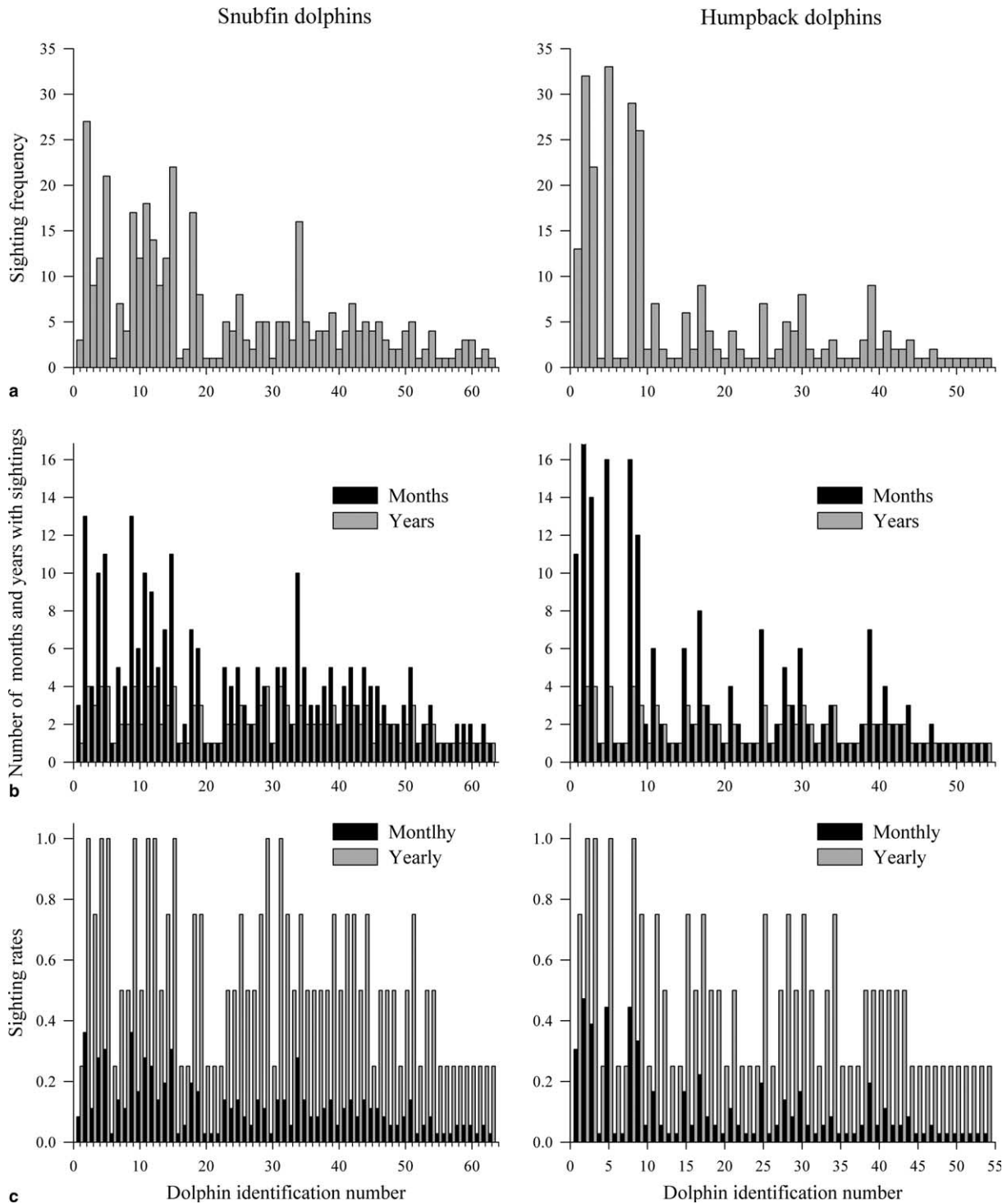
Species	CV	Rate of change ( $r$ )	Number of surveys required ( $n$ )	Number of years to detection ( $t(n - 1)$ )	Total % change at detection for decreasing population $(1 - r)^{t(n-1)} - 1$	Total % change at trend detection for increasing population $(1 + r)^{t(n-1)} - 1$
Snubfin	0.08	0.05	7	6	-0.28	0.36
		0.1	5	4	-0.32	0.41
		0.15	4	3	-0.34	0.43
		0.2	3	2	-0.35	0.42
Humpback	0.14	0.05	11	10	-0.39	0.60
		0.1	7	6	-0.45	0.73
		0.15	5	4	-0.49	0.78
		0.2	4	3	-0.52	0.81

Data variability is specified at CV = 0.08 for snubfin dolphins and 0.14 for humpback dolphins. These CVs correspond to the highest level of precision obtained for the abundance estimates of snubfin and humpback dolphins (see Table 1). The probability of Type I ( $\alpha$ ) and II ( $\beta$ ) errors was set at the 0.05 level.

a Estimates were derived from:

$$r^2 n^3 \geq 12CV^2 (Z_{\alpha/2} + Z_{\beta})^2,$$

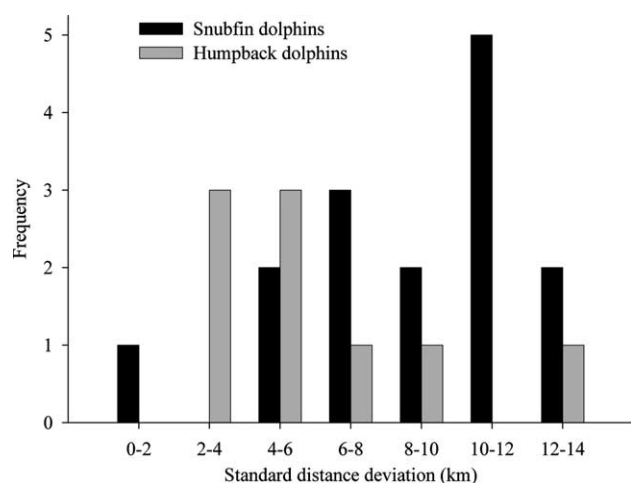
where  $r$  is the annual rate of population change,  $n$  is the number of population estimates, CV is the coefficient of variation of the estimated total population size,  $Z_{\alpha/2}$  is the one-tailed probability of making a Type I error ( $\alpha$ ) and  $Z_{\beta}$  is the probability of making a Type II error ( $\beta$ ). The probability of Type I and II errors was 0.05 as this is the standard level of  $\alpha$  and  $\beta$  used to claim a statistically significant effect, and high statistical power (Power =  $1 - \beta = 0.95$ ).



**Fig. 4 – Sightings of 63 and 54 snubfin and humpback dolphins identified in Cleveland Bay between 1999 and 2002: (a) total number of sightings of all identified individuals; (b) number of months and years in which each individual dolphin was sighted; (c) number of months and years a dolphin was identified as the proportion of the total number of months and years surveyed.**

indicated that many of the snubfin dolphins identified were seen in more than one calendar year. Humpback dolphins showed a similar pattern, with low monthly sighting rates ( $0.10 \pm 0.02$  sightings per month), and relatively high sightings across years ( $0.46 \pm 0.03$  sightings per year) (Fig. 4c).

The standard deviation of the distance of each individual dolphin location from their mean centre indicated that over 50% of the snubfin and humpback dolphins sighted on at least eight occasions were found within less than 10 km of their mean centre (Fig. 5).



**Fig. 5** – Frequency distribution of the standard deviation of the distance of each individual dolphin location from their mean centre (i.e., standard distance deviation) for all snubfin dolphins ( $n = 15$ ) and humpback dolphins ( $n = 9$ ) identified  $\geq 8$  times in Cleveland Bay between 1999 and 2002.

### 3.6. Residence times

The lagged identification rate of snubfin dolphins fall after lags of approximately 3 to 30 days and then levelled off above zero at longer time lags (Fig. 6a). This pattern suggests that animals may spend periods of up to 30 days in the bay before leaving the study area. The lagged identification rate of humpback dolphins showed a similar pattern but with different residence times. For humpback dolphins it appears that animals left the study area after periods of 10–140 days (Fig. 6b). For both species the lagged identification rate levelled off above zero, suggesting that some animals are permanent residents and/or others reimmigrate into the study area after longer time lags.

Of the two models applied to the data, the model curve of emigration and reimmigration into the study area fitted the data best for both species (Fig. 6). This model also showed the lowest AIC<sub>c</sub> values (snubfin: 17841; humpback: 17146) in comparison to emigration/mortality models (snubfin: 17913; humpback: 17183). Estimates of mean population size and residence times from this model indicate that approximately 14 ( $14.3 \pm \text{SE} = 1.77$ , 95% CI = 11.6, 18.5) snubfin dolphins and 10 ( $10.1 \pm \text{SE} = 1.87$ , 95% CI = 7.7, 14.1) humpback dolphins were in the study area at any one time, and that animals could spend from a few days to over a month inside the study area before leaving. Snubfin dolphins appeared to reside inside the study area for periods of 30 days ( $30.3 \pm \text{SE} = 24.70$ , 95% CI = 17.2, 56.2), and spend periods of 48 days ( $47.8 \pm \text{SE} = 29.7$ , 95% CI = 27.5, 85.3) outside the study area before entering back into it. Humpback dolphins had considerably longer residence times inside the study area of 141 days ( $\pm \text{SE} = 110.3$ , 95% CI = 88.7, 281.1), and periods of 109 days ( $\pm \text{SE} = 47.7$ , 95% CI = 68.1, 212.7) outside the study area.

## 4. Discussion

### 4.1. Estimates of abundance

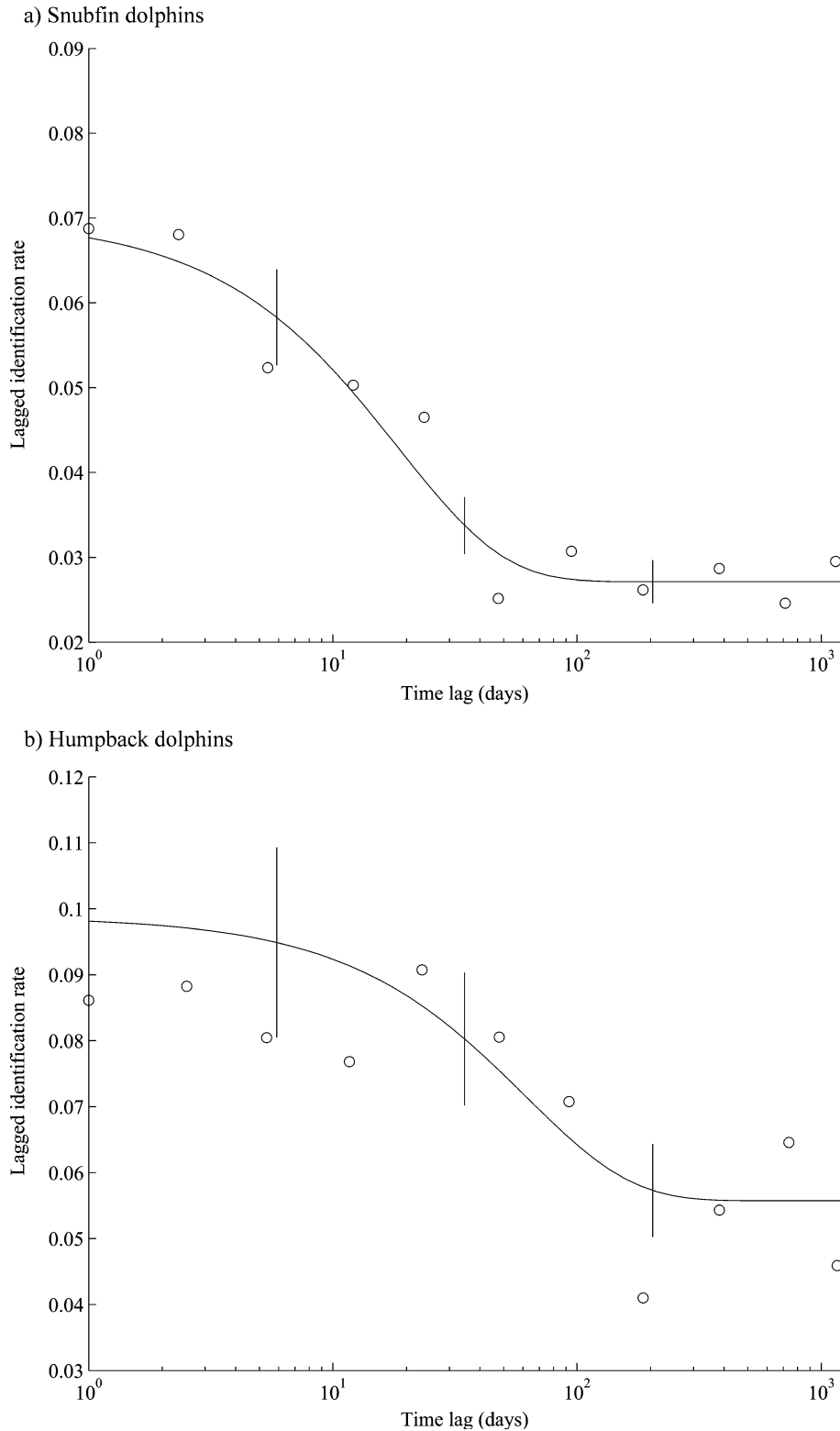
Our results indicate that a small number of snubfin and humpback dolphins inhabit the coastal waters of Cleveland Bay. From detailed examination of the assumptions involved in mark recapture analyses with open population models, we were able to derive what we consider to be relatively unbiased and precise abundance estimates for both species. We estimated that substantially less than a hundred individuals of each species used the study area between 1999 and 2002.

With no previous estimates of abundance, it is impossible to assess if populations of both species in Cleveland Bay have been stable, increasing or decreasing. Analysis of data from three aerial surveys along most of the eastern Queensland coast between 1987 and 1995 suggest population(s) of humpback dolphins may be in decline (Corkeron et al., 1997). Local populations of both species have been subject to anthropogenic mortality in the past (Heinsohn, 1979; Paterson, 1990). We regard some mortality in commercial gillnets as inevitable because nets are mainly set in waters close to the coast and there is evidence that both genera are vulnerable to gillnetting practices (Amir et al., 2002; Smith et al., 2003). Furthermore, incidental bycatch of these species has been recognised, and discussed with the authors (PJC and HM), by gillnetters elsewhere in Queensland.

### 4.2. Trends in abundance

The data collected in this study do not provide an insight into the current trends of local abundance of snubfin and humpback dolphins. The analysis of statistical power of capture-recapture methods indicate that population trends will be extremely difficult to detect in less than three years, unless changes in population size are very high ( $>20\%$  p.a.). At such high levels of annual change, local populations of snubfin and humpback dolphins could have decreased to very low levels by the time trend is detected.

The estimation of trends becomes more complex if we take into account the apparent open nature of both populations. The initial increase in the discovery rate of new individuals of both species during 1999 (Fig. 2) is an attribute of the beginning of the study. However, the alternating increases and plateaus in the discovery curve later in the study suggest a regular influx of new individuals to the study area. Site fidelity and residence patterns of identified individuals suggest that there is substantial movement of animals out of the study area, but that a high proportion tends to return following a model of emigration and reimmigration. Two snubfin dolphins identified in this study have been photo-identified in Bowling Green Bay, immediately south of Cleveland Bay (Parra and Corkeron, 2001). It is therefore important that future survey coverage include areas to the north and south of the study area to assess population structure and how movement of individuals between these areas might affect abundance estimates at a local level.



**Fig. 6 – Lagged identification rates (o) for (a) adult snubfin dolphins and (b) humpback dolphins in coastal waters of Cleveland Bay, together with the expected lagged identification rates and estimated standard errors (bars) from emigration and reimmigration models fitted to the data using maximum likelihood.**

**4.3. Site fidelity and residence patterns**

Most individual dolphins identified in Cleveland Bay do not reside in the study area permanently, but use the study area

regularly from year to year. Modelling of sighting patterns suggested that movement patterns of most individuals of both species followed a model of emigration and reimmigration into the study area. Thus, the coastal waters of Cleveland

Bay appear to be an important part of the home ranges of both snubfin and humpback dolphins in the region around Townsville.

The large proportion of humpback dolphins observed only once (41%) indicates that there is a high number of individuals that either die, or spend most of their time outside the study area either in offshore or in adjacent waters to Cleveland Bay. In contrast, the smaller proportion of snubfin dolphins observed only once (22%) indicates that most individuals use the coastal waters of Cleveland Bay. Eight humpback dolphins and three snubfin dolphins were found dead in the Townsville region and surrounding areas between 1999 and 2002, so some emigration may be mortality (Haynes et al., 1999; Haynes and Limpus, 2000, 2002; Limpus et al., 2003).

Although we expect both species also occur in offshore waters of Cleveland Bay there is evidence that animals occur mainly in waters close to the coast. Pilot studies in Cleveland Bay totalling 14 h and 163 km of line transect that covered waters up to 10 km from the coast yielded no sightings beyond 5 km (Parra unpublished data). Additionally most sightings of snubfin and humpback dolphins made during aerial surveys (Corkeron et al., 1997; Parra et al., 2002) and boat-based line transect surveys including offshore waters (waters >10 km from the coast) of different areas along the Queensland coast, occurred in waters within 6 km from the nearest coastline (Corkeron et al., 1997; Parra et al., 2002; Parra, 2005). Thus, it is likely that the proportion of humpback dolphins and snubfin dolphins seen only once are occasional visitors spending most of their time in coastal waters outside Cleveland Bay.

The overall low standard distance deviations displayed by frequently sighted individuals of both species suggest that individuals repeatedly come back to particular areas within the study area. This localised pattern is indicative of preferential use of some areas by individuals. These results correspond with analysis of space use patterns of snubfin and humpback dolphins at the population level in Cleveland Bay (i.e., schools of dolphins instead of individuals were used for analysis of space use), where it was shown that use of space by both species was not random and schools tended to concentrate their activities in certain core areas (Parra, 2005).

The spatial and temporal variability in the quality of a site, and breeding and foraging success (Switzer, 1997a,b; Irons, 1998) have been suggested to affect site fidelity. Cleveland Bay is a large estuarine system receiving freshwater input from several rivers and creeks and fish are abundant (Robertson and Duke, 1987, 1990). Foraging and socialising (i.e., socio-sexual behaviour) are among the predominant behaviours observed for snubfin and humpback dolphins in Cleveland Bay (Parra, 2005). Thus, both habitat characteristics and species behaviour suggest that individuals of both species may return regularly to the study area because they have higher chances of finding prey and/or mating conspecifics.

#### 4.4. Implications for conservation

Small populations are more prone to extinction than large stable populations because of loss of genetic variability and environmental and demographic stochasticity (Caughley

and Gunn, 1996). Recent studies across many vertebrate taxa suggest that the minimum size required for a population to be viable (i.e., the smallest size a population can have to have a 99% probability of persistence for 40 generations) in the long-term is thousands to tens of thousands of individuals (Reed et al., 2003). Population viability analysis of well known coastal dolphin species (i.e., bottlenose dolphin, *Tursiops truncatus*, and Hector's dolphin, *Cephalorhynchus hectori*) indicate that populations of less than a hundred animals face very high extinction probabilities (Thompson et al., 2000; Burkhart and Slooten, 2003). Our low estimates raise concerns about the long-term survival of both species in this local region and emphasizes the need to increase research and conservation efforts in Australia if conservation is to be successful.

Although it is difficult to be certain about the status of snubfin and humpback dolphins in Queensland waters, our results for Cleveland Bay indicate that, at least at a local scale, populations of both of these species are small. Population estimates at a regional level (e.g., Queensland) are likely to be in the order of thousands rather than tens of thousands. This conclusion is substantiated by: (1) the low numbers of snubfin and humpback dolphins sighted during aerial surveys covering most of the east Queensland Coast between 1987 and 1995 (i.e., 29 sightings of snubfin dolphins and 54 sightings of humpback dolphins (Corkeron et al., 1997; Parra et al., 2002); (2) the low number of sightings during boat-based line transect surveys in selected areas of northeast Queensland (22 sightings of Irrawaddy dolphins and 14 sightings of humpback dolphins, Parra, 2005); and (3) the low estimates of abundance for humpback dolphins in Moreton Bay, an area approximately four times the size of Cleveland Bay, (i.e., 119 individuals for the period of August 1985 to February 1987, and 163 individuals for May 1984 to February 1986, Corkeron et al., 1997).

The low population numbers of snubfin and humpback dolphins and our inability to detect trends reinforce the assertions that scientific proof of decline or increase should not be a necessary criterion for enacting conservation measures (Taylor and Gerrodette, 1993; Wilson et al., 1999; Thompson et al., 2000). Against this background, the first priority of managers should be to reduce and control all direct threats (e.g., gillnets, shark nets) to local populations while minimising the impacts of management decisions on different stakeholder groups.

The recurrent use of coastal waters of Cleveland Bay by both species from year to year poses some concerns about the long-term survival of local populations if current habitat quality is not improved, or at least maintained. Species with high levels of site fidelity are vulnerable to population declines due to habitat degradation and loss, particularly when those species occupy relatively restricted habitats (Warkentin and Hernandez, 1996). The various habitats within the home range of local populations of snubfin and humpback dolphins are unlikely to be of the same quality. Consequently, degradation and loss of coastal habitats in Cleveland Bay can lead to an increase in distance among habitable patches and/or reduction in number of remnant habitats (i.e., habitat fragmentation; Andr n, 1994). For example, a large scale loss of seagrass habitat in Hervey Bay, Queensland, following a

cyclone and two floods resulted in unprecedented deaths and decline of the local dugong population, *Dugong dugon* (Preen and Marsh, 1995).

As individuals of both species spent considerable time outside the study area, management strategies aimed at conserving dolphins within Cleveland Bay must include human activities in surrounding areas. The current level of protection offered to snubfin and humpback dolphins in Cleveland Bay is relatively good. Because of its status as a Dugong Protected Area Type A since 1997, gillnetting is restricted in Cleveland Bay. In addition, shark nets to protect bathers were replaced with baited drumlines in 1992 and the number of dolphins killed at a regional level due to the Queensland Shark Control Program has declined (Gribble et al., 1998). However, adjacent areas to Cleveland Bay offer different levels of protection regarding mesh netting practices. For example, mesh netting activities are allowed to continue with some safeguards and restrictions in Bowling Green Bay, a Dugong Protected Area Type B to the south of Cleveland Bay. In Halifax Bay, North of Cleveland Bay, there are no regulations regarding mesh netting practices per se. Although 38% of coastal waters (i.e., waters within 10 km from the mainland) along the urban coast of the Great Barrier Reef World Heritage Area are protected from gillnetting (Alana Grech, personal communication 2005), entanglement threats in waters adjacent to Cleveland Bay pose some risk to the maintenance of local populations.

The Townsville region is one of the largest growing coastal areas in northeast Queensland (145,000 inhabitants) with an average annual growth rate of 2–3% over the past 30 years (King, 2003). Given the small population sizes of snubfin and humpback dolphins estimated in Cleveland Bay, efforts to maintain viable populations of both species will require improvements to current levels of protection inside as well as adjacent areas. Such protection must not only involve the management of gillnetting activities, but of other human activities adjacent to the coast that have been identified as potentially threatening (pollution, vessel traffic, and overfishing, Parra et al., 2002, 2004).

Although the preservation of suitable habitats is necessary, the persistence of snubfin and humpback dolphins in Australian waters cannot occur without an understanding of their distribution, demography and population genetics at local and regional levels. Future research in these areas will improve our capacity to provide effective management actions towards the conservations of these two species.

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