THE RAFFLES BULLETIN OF ZOOLOGY 2002 Supplement No. **10**: 141-154

DISTRIBUTION OF IRRAWADDY DOLPHINS, *ORCAELLA BREVIROSTRIS*, IN AUSTRALIAN WATERS

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ABSTRACT. – Records from strandings, museum specimens, sighting databases and unpublished sightings of aerial surveys were compiled and used to review the distribution and population status of Irrawaddy dolphins, *Orcaella brevirostris*, in Australian waters. Stranding and museum specimen records indicate that Irrawaddy dolphins occur only in the northern half of Australia, from approximately the Brisbane River (27° 32'S, 152° 49'E) on the east coast to Broome (17° 57'S, 122° 14'E) on the west coast. Aerial surveys demonstrate that Irrawaddy dolphins occur mainly in protected, shallow, coastal waters, close to river and creek mouths, which appear to be an important habitat for the species. Irrawaddy dolphins tend to form relatively small groups of 1-10 animals with occasional aggregations of up to 14 animals. The status of Irrawaddy dolphins in Australian waters is difficult to assess, because most data have been collected opportunistically. However, the low number of sightings during aerial surveys, in comparison with observations of other sympatric marine mammals, such as Indo-Pacific humpback dolphins (*Sousa chinensis*), suggest that Irrawaddy dolphins are relatively uncommon in Australian waters, or possibly are inadequately sampled on aerial surveys.

KEY WORDS. – Australia, distribution, status, Irrawaddy dolphins, *Orcaella brevirostris,* strandings, aerial surveys.

INTRODUCTION

Irrawaddy dolphins, *Orcaella brevirostris*, occur in the tropical-subtropical waters of the Indo-West Pacific region, from the Bay of Bengal in India, to the northeastern Australian coast (Stacey & Leatherwood, 1997; Stacey & Arnold, 1999). The species is mainly found in shallow, brackish, estuarine and coastal waters, and in some major river systems of Southeast Asia (Stacey & Arnold, 1999). Genetic and morphologic evidence suggest that Irrawaddy dolphins belong to the family Delphinidae (Arnold & Heinsohn, 1996; LeDuc et al., 1999). However, the taxonomic status of Irrawaddy dolphins, at the intraspecifc level, remains unclear (Stacey & Arnold, 1999). The present consensus is to recognize, *O. brevirostris,* as the only species in this genus (Rice, 1998). However, recent studies of skull morphology suggest possible specific differences between Australia/New Guinea and Southeast Asian forms (Beasley et al., 2002). Throughout most of their range, little is known of the biology and status of Irrawaddy dolphins. Anecdotal evidence suggests a decline in Chilka Lake, India (Dhanpanani, 1992) and the Gulf of Thailand (Stacey & Leatherwood, 1997). Threats to populations vary regionally, and include direct takes, incidental catches, live captures for display facilities, and habitat degradation (Stacey & Leatherwood, 1997).

Although the distribution of the Irrawaddy dolphin in Australia is poorly known, it has been recorded from Broome (17° 57'S, 122° 14'E) in Western Australia, along the northern coastline near Darwin and the Gulf of Carpentaria, and off the eastern coast as far south as the Brisbane River (27° 32'S, 152° 49'E) (Stacey & Arnold, 1999) (Fig. 1a). The only attempt to estimate abundance, in Australian waters, was in the western Gulf of Carpentaria (Freeland & Bayliss, 1989). An estimate of approximately 1000 individuals was

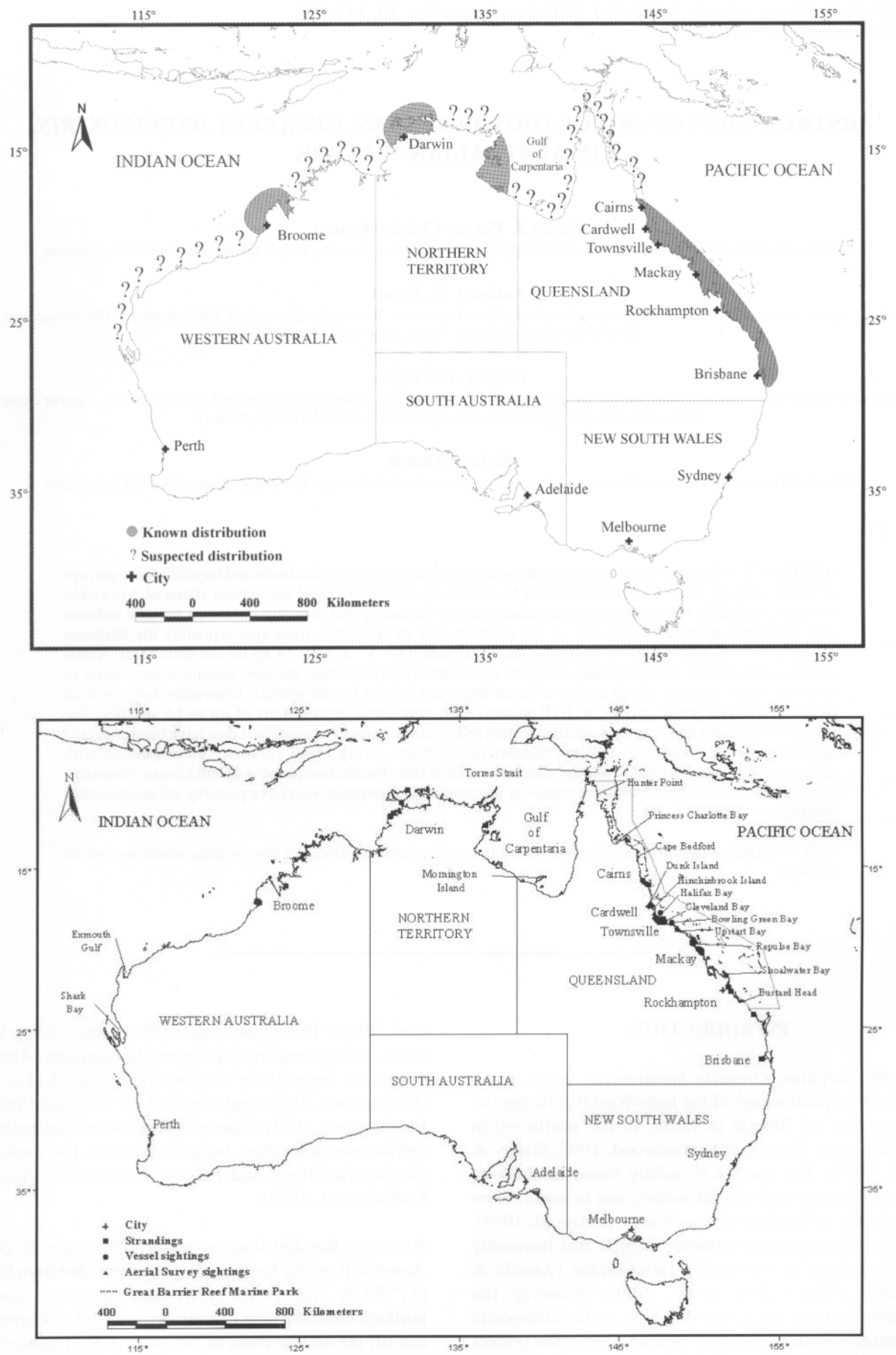

Fig. 1. Distribution of Irrawaddy dolphins in Australian waters: a) known distribution based on Marsh et al., 1989; Freeland & Bayliss, 1989; Paterson, 1994; Paterson et al., 1998; Stacey & Leatherwood, 1997; Stacey & Arnold, 1999. Question marks indicate areas of probable, but unconfirmed, distribution, b) spatial distribution of Irrawaddy dolphins based on stranding and museum specimen records obtained between 1948 and 1999, and unpublished vessel and aerial survey sightings between 1986 and 2000.

calculated, based on sightings from an aerial survey. This estimate is questionable however, due to the difficulties in identifying dolphin species from the air in turbid waters without circling each group. Irrawaddy dolphins are inconspicuous, have unpredictable surfacing patterns, low surfacing profiles and, in general, are elusive (Dhandapani, 1992; Beasley & Jefferson, 1997; Kreb, 1999). The distribution of Irrawaddy dolphins in Australian waters overlaps those of Indo-Pacific humpback (*Sousa chinensis*) and bottlenose dolphins (*Tursiops* spp.), and dugongs (*Dugong dugong*), thereby increasing the likelihood of species misidentification.

Despite the apparently wide distribution of Irrawaddy dolphins in waters of northern Australia, information on their spatial distribution and population status is poorly documented. Irrawaddy dolphins are considered "Insufficiently Known" in the Action Plan for Australian Cetaceans (Bannister et al., 1996) and are listed as "Rare Wildlife" under the *Queensland Nature Conservation (Wildlife) Regulation 1994* (Environmental Protection Agency, PO Box 155, Brisbane, Albert St, QLD 4002, Australia).

This paper reviews available records on the spatial distribution of Irrawaddy dolphins in Australian waters. Records of specimens found in museums, stranding and sighting databases held by wildlife agencies, and unpublished sighting records from aerial surveys were compiled and used for this purpose. The information available is limited, and baseline data are lacking. In order to develop effective conservation measures for Irrawaddy dolphins in Australian waters, an understanding of this species' distribution, movement patterns, relative abundance and levels of anthropogenic mortality is required as a matter of urgency.

METHODS

Stranding and museum specimen records. – Stranding and museum specimen records of Irrawaddy dolphins were obtained from the following museums: Australian Museum (Sydney, Australia), Museum of Tropical Queensland (Townsville, Australia), Queensland Museum (Brisbane, Australia), Museum and Art Galleries of the Northern Territory (Darwin, Australia), Western Australia Museum (Perth, Australia), and the National Museum of Natural History (Washington D.C., USA) (Appendix 1). Additional records were provided by the Queensland Parks and Wildlife Service and the Parks and Wildlife Commission of the Northern Territory.

Sighting records. – Sighting records were obtained from vessel patrols made by the Queensland Parks and Wildlife Service between 1989 and 2000, and opportunistic vessel surveys by one of the authors (AP) in 1995 and 1998 in the Townsville-Cardwell region (Appendix 2). Identification was carried out by experienced observers, and was confirmed by close approach of the dolphin group (10-20 metres). Sighting locations (latitude and longitude), in all instances, were determined by Global Positioning Systems (GPS).

Aerial surveys. - Sighting records of Irrawaddy dolphins were extracted from unpublished data of aerial surveys conducted in western, northern and eastern Australia between 1986 and 1998 (Appendix 3). All surveys were designed to estimate the distribution and abundance of dugongs. Most of the aerial surveys were carried out using strip transect aerial survey methodology as detailed by Marsh & Sinclair (1989a, b) and Marsh & Saalfeld (1989). In addition, surveys in some regions used a combination of shoreline and strip-transect methods. Survey effort was not evenly distributed across time and survey areas (see Appendix 3).

During all surveys, group size, group composition (number of calves and adults), position in the water column (on the surface or underwater) and the reliability of species identification (certain or uncertain) were recorded. Dolphins were identified to species based on their size, shape and colouration. Irrawaddy dolphins were distinguished from other dolphin species by their bulbous head, small dorsal fin, and light to dark brown colouration. In most cases, dolphin groups were not circled and data were collected during the single overpass of each group. In some cases, Preen (1999a, 199b) circled dolphin groups to confirm identifications. The exact sighting location of each Irrawaddy dolphin group was calculated using the equations described in Appendix 4.

Spatial analysis. – ArcView Geographic Information Systems software (GIS) (ESRI, 1996) was used for display and analysis of all sighting records. All stranding records, for which locations (latitude and longitude) were available, were plotted on a digital map of Australia (scale = 1:1,000,000). Sighting records from vessel patrols and aerial surveys were plotted on a digital map of Australia (scale = 1:250,000). The approximate distance of vessel and aerial survey sightings locations from the closest point of land (i.e., mainland or island) and nearest freshwater source (i.e., river and creek mouths) was estimated using the inbuilt measuring function of ArcView. Digital map data were obtained from the Australian National Mapping Agency (Australian Land Information Group, Scrivener Building, Dunlop Court, Fern Hill Park, Bruce ACT 2617, PO Box 2, Belconnen ACT 2616, Australia). Water depths were estimated using hydrographic charts from the Australian Hydrographic Office (The Australian Hydrographic Office, 8 Station Street Wollongong NSW 2500, Australia).

RESULTS

Stranding and museum specimen records. – Eighty-one Irrawaddy dolphin records have been collected by museums and government agencies, between 1948 and 1999 (Appendix 1). The spatial distribution of strandings and museum specimens ranged from the Brisbane River (27° 32'S, 152° 49'E) on the east coast, throughout most of the Queensland coast, Northern Territory, to Broome (17° 57'S, 122° 14'E) on the west coast (Fig. 1b).

Sighting records. – Sighting records included 10 confirmed

Table 1. Summary statistics on group size, distance from the nearest point of land (either mainland or island) and distance from the nearest freshwater source (either river or creeks mouth) for sighting records obtained from vessel patrols made by the Queensland Parks and Wildlife Service between 1989 and 2000, and opportunistic vessel surveys by A. Preen between 1995 and 1998 in the Townsville-Cardwell region, and aerial surveys sighting records obtained from aerial surveys conducted in western, northern and eastern Australia between 1986 and 1998 (*in italics*).

Variable	*Sighting records*					
	Mean	Median	Mode	Range	± SE	n
Group size	4.9	5	5	1-10	0.79	10
	5.4	*5*	*1*	*1-14*	*0.75*	*29*
Distance to the nearest point of land (km)	1.3	1.3	N/A	0.6-2.7	0.18	10
	4.5	*2.5*	*N/A*	*0.3-22.5*	*0.95*	*29*
Distance to the nearest freshwater source (km)	9.1	4.2	N/A	1.4-46.	4.32	10
	9.8	*5*	*N/A*	*0-43.2*	*1.90*	*29*

sightings of Irrawaddy dolphins in the Townsville-Cardwell region (Appendix 2). These sightings occurred mostly in coastal waters in or near Bowling Green Bay, Cleveland Bay, Halifax Bay, and the Hinchinbrook Channel, with the exception of one sighting off the Great Palm Islands (18° 44'S, 146° 41'E) (Fig. 1b). Although group sizes and distances to land and freshwater were not normally distributed, and thus means may not represent the best estimates, they are reported here with the median, mode and range for comparative purposes (Table 1). The mean group size was 4.9 (SE = ±0.79). Distances to the nearest point of land ranged between 0.6 km and 2.7 km, with a mean of 1.3 km (SE = ±0.18). The mean distance to the nearest freshwater source was 9.1 km (SE = ± 4.32). Seventy percent (n = 7) of the sightings occurred within 5 km from the nearest freshwater source, and 90 % of the sightings (n = 9) occurred in waters less than 10 m deep.

Aerial surveys. – Thirty-three sightings of Irrawaddy dolphins were made during aerial surveys. Of these, 29 were classified as certain and four as uncertain (Appendix 3). Only certain sightings were used in this analysis.

All sightings occurred along the Queensland coast, in the Gulf of Carpentaria, and along the Great Barrier Reef region (Fig. 1b). The number of sightings varied among different areas, with 82.7% (n = 24) of the sightings occurring along the Great Barrier Reef region. Within the Great Barrier Reef region, 62.5% (n = 15) of all sightings were recorded in the Townsville-Cardwell region, where survey effort was greatest. Aerial survey sightings north of Cairns, near Princess Charlotte Bay, and along the eastern Gulf of Carpentaria, confirm the suspected occurrence of Irrawaddy dolphins in these areas.

Group sizes ranged from 1-14, with an overall mean of 5.4 (SE = ±0.75) (Table 1). The most frequently-encountered groups were singles and pairs (37.9%, n = 11) followed by groups of 6 to 10 animals (34.4%, n = 10) (Fig. 2).

The mean distance to the nearest point of land was 4.5 km (SE = ±0.95) (Table 1). Of the 29 sightings 89.6% (n = 26) of all groups observed were within 10 km of shore (Fig. 3a). Three groups were observed up to 23 km offshore. The mean distance to the nearest freshwater source was 9.8 km (SE = ±1.90), with distances ranging from 0 to 43.2 km (Table 1, Fig. 3a). Sixty-nine percent (n = 20) of all sightings occurred in waters less than 10 m deep (Fig. 3b).

DISCUSSION

Distribution. – Irrawaddy dolphins occur in the coastal waters of northern, eastern, and western Australia, from the Brisbane River (27° 32'S, 152° 49'E) on the east coast to Broome (17° 57'S, 122° 14'E) on the west coast. Irrawaddy dolphins are known to occur in several major river systems of Southeast Asia (Stacey & Arnold, 1999). In Australia Irrawaddy dolphins have been documented almost exclusively in coastal and estuarine waters and it is doubtful if they venture very far upstream in river systems. The occurrence of Irrawaddy dolphins in the upper tidal reaches of the Brisbane River during 1997 (Paterson et al., 1998) appears to be extralimital. There have been no further records in the Brisbane River area since 1997, and it is likely that the dolphins were vagrants (Paterson et al., 1998). The paucity of records for areas between the Gulf of Carpentaria and Broome reflects the limited research effort in this area, rather than a distributional hiatus.

Within Australian waters, Irrawaddy dolphins were mostly observed close to the coast in sheltered, shallow waters, particularly near the mouths of creeks and rivers. This distribution pattern is probably related to the feeding habits of the species, with many of the fish prey items in Australia (i.e., Engraulidae, Clupeidae, Chirocentridae, Anguillidae, Hemirhampidae, Leiognathidae, Apogonidae, Pomadasydae, Terapontidae, Sillaginidae) (Heinsohn, 1979; Marsh et al., 1989), typically associated with shallow coastal waters and estuaries in tropical regions. Protected, inshore, shallow estuarine waters appear to represent critical habitat for the species, a result consistent with reports from other geographic regions (Stacey & Leatherwood, 1997; Stacey & Arnold, 1999).

The occurrence of Irrawaddy dolphins farther than 10 km

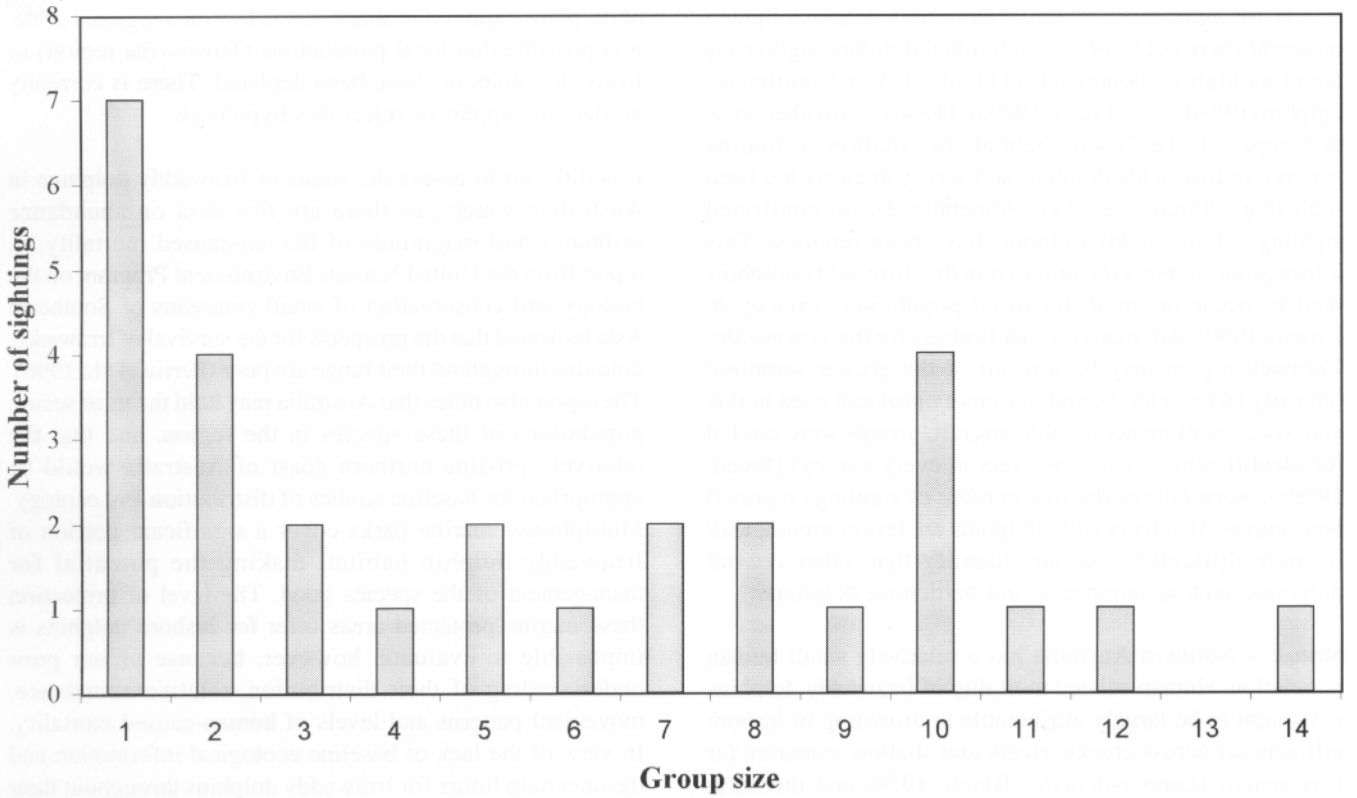

Fig. 2. Distribution of group sizes of Irrawaddy dolphins observed during aerial surveys in Australian waters.

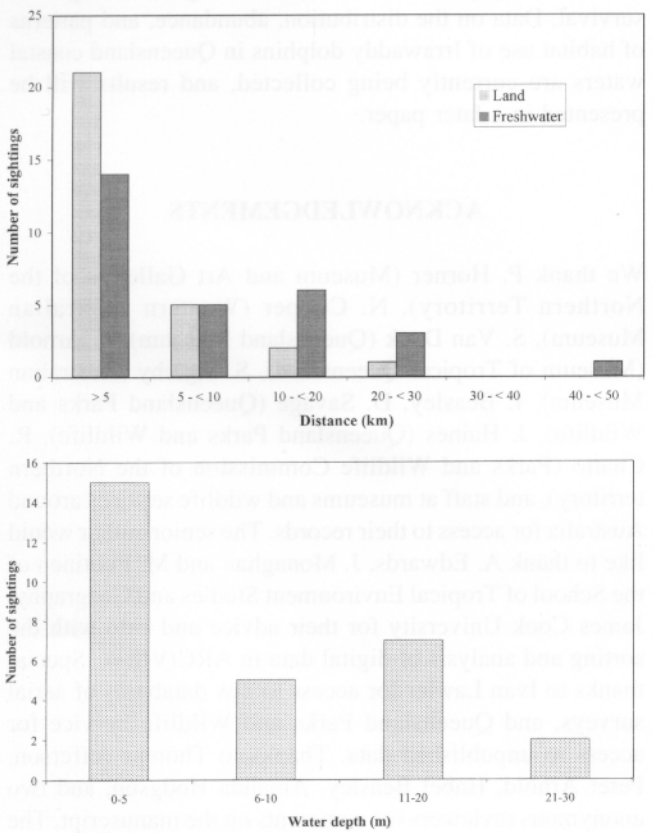

Fig. 3. Distribution of sightings of Irrawaddy dolphins observed during aerial surveys, in relation to the distance from the nearest point of land and freshwater source (a), and water depth (b).

from shore, and/or in waters deeper than 20 m, was particular to the Great Barrier Reef region. Reefs, sandflats and continental islands are common in this region. Thus, the depth of the water in these areas is mainly shallow even in offshore waters, and dolphins would not have to travel long distances in relatively deep, and exposed waters before re-entering shallow coastal waters.

Group size. – Irrawaddy dolphins form relatively small groups of 1-10 animals, with aggregations of up to 14 animals observed occasionally. This range of group sizes is similar to that in coastal (see Beasley & Jefferson, 1997) and riverine forms, (Stacey, 1996; Smith et al., 1997; Kreb, 1999), suggesting that Irrawaddy dolphins form comparable size groups regardless of whether they inhabit a coastal or riverine environment. The occasional occurrence of large groups seems to be associated with socializing behaviour, probably mating. Most of the large groups observed in the Townsville-Cardwell area during aerial surveys involved individuals in a very tight formation with extensive physical contact (Preen, personal observations).

Abundance. – The available data are insufficient to estimate the abundance of Irrawaddy dolphins in Australian waters. Data from aerial surveys suffer from an absence of information on visibility biases, low numbers of sightings, and problems of species identification from the air in turbid waters.

In most of the areas in Australian waters where the distribution of Irrawaddy and humpback dolphins overlaps, there are fewer sightings of Irrawaddy dolphins. However, this is not always the case. In the Townsville-Cardwell

region, the number of individual Irrawaddy dolphins sighted on aerial surveys (87 of 311 individual dolphins sighted) is about as high as humpback (111 of 311) and bottlenose dolphins (95 of 311) (Preen, 1999a). However, in other areas that appear to be "good" habitat (i.e. shallow, estuarine waters) for Irrawaddy dolphins and survey intensity has been high (e.g., Shoalwater Bay, Appendix 3), no confirmed sightings of Irrawaddy dolphins have been reported. This information supports the impression that Irrawaddy dolphins tend to occur in small, localised populations (Stacey & Arnold, 1999). Alternatively, our findings for the Townsville-Cardwell region may be a result of the greater sampling intensity (Appendix 3), and the survey protocol used in this area (i.e., small manoeuvrable aircraft, groups were circled for identification, same observers in every survey) (Preen, 1999a). Nonetheless, the low number of sightings reported here suggest that Irrawaddy dolphins are less common, and/or more difficult to see and identify than other coastal dolphins, such as humpback and bottlenose dolphins.

Status. – Northern Australia has a relatively small human population. Human-related mortality of Irrawaddy dolphins is thought to be largely attributable to drowning in inshore gill-nets set across creeks, rivers and shallow estuaries for barramundi (*Lates calcarifer* Bloch, 1970) and threadfin salmon (*Polynemus sheridani* Maclaey, 1884 and *Eleutheronema tetradactylum* Shaw, 1804) (Anderson, 1995; Hale, 1997), and in shark nets set for bather protection (Paterson, 1990). However, there are no estimates of Irrawaddy dolphin bycatch. Regulations to reduce bycatch, such as net attendance rules and gear modifications have been introduced, but enforcement is lacking in remote areas (Hale, 1997). The establishment of a system of two-tiered Dugong Protected Areas (DPAs) in the inshore waters of the Great Barrier Reef Marine Park, where net fishing has been prohibited in 2,407 km^2 and restricted in an additional 2,243 km^2 (Marsh, 2000), may provide some protection to Irrawaddy dolphins along the urban coast of Queensland. Many of the sightings of Irrawaddy dolphins along the Great Barrier Reef region occurred within DPAs (i.e., Hinchinbrook, Cleveland Bay, Bowling Green Bay, Upstart Bay).

Between 1967 and 1992 at least 544 cetaceans were caught in shark nets set for bather protection along the Queensland coast (Paterson, 1990; Anon. 1992). A recent analysis of the effects of this program on non-target species (Gribble et al., 1998) estimated that between 1962 and 1995, an average of 19 dolphins were caught per year. Although the species composition for most dolphin catches prior to 1992 is unknown, 15 of 24 dolphin catches in the Townsville region between 1968-1976 were Irrawaddy dolphins (Heinsohn, 1979). The number of dolphins killed has declined over time, coincident with the replacement of most shark nets with baited drumlines. However, an analysis of the temporal change in catch per unit-effort has not been attempted. Between 1992 and 1995, Gribble et al. (1998) estimated that 1.3 Irrawaddy dolphins were caught per year in shark nets along the Queensland Coast. Although the annual number of dolphins captured in shark nets is low on a regional scale, it is possible that local populations (Townsville region) of Irrawaddy dolphins have been depleted. There is currently no data to support or reject this hypothesis.

It is difficult to assess the status of Irrawaddy dolphins in Australian waters, as there are few data on abundance estimates and magnitude of human-caused mortality. A report from the United Nations Environment Program on the biology and conservation of small cetaceans of Southeast Asia indicated that the prospects for the survival of Irrawaddy dolphins throughout their range are poor (Perrin et al., 1996). The report also notes that Australia may hold the most secure populations of these species in the region, and that the relatively pristine northern coast of Australia would be appropriate for baseline studies of distribution and ecology. Multiple-use marine parks cover a significant portion of Irrawaddy dolphin habitat, making the potential for management of the species good. The level of protection these marine protected areas offer for inshore dolphins is impossible to evaluate, however, because of our poor understanding of their distribution, relative abundance, movement patterns and levels of human-caused mortality. In view of the lack of baseline ecological information and the uncertain future for Irrawaddy dolphins throughout their range, research actions and conservation measures in Australia may prove crucial for ensuring their long-term survival. Data on the distribution, abundance, and patterns of habitat use of Irrawaddy dolphins in Queensland coastal waters are currently being collected, and results will be presented in a later paper.

ACKNOWLEDGEMENTS

We thank P. Horner (Museum and Art Galleries of the Northern Territory), N. Cooper (Western Australian Museum), S. Van Dyck (Queensland Museum), P. Arnold (Museum of Tropical Queensland), S. Ingleby (Australian Museum), I. Beasley, D. Savage (Queensland Parks and Wildlife), J. Haines (Queensland Parks and Wildlife), R. Chatto (Parks and Wildlife Commission of the Northern territory), and staff at museums and wildlife services around Australia for access to their records. The senior author would like to thank A. Edwards, J. Monaghan and M. Puotinen of the School of Tropical Environment Studies and Geography, James Cook University for their advice and help with the sorting and analysis of digital data in ARC/VIEW. Special thanks to Ivan Lawler for access to raw databases of aerial surveys, and Queensland Parks and Wildlife Service for access to unpublished data. Thanks to Thomas Jefferson, Peter Arnold, Isabel Beasley, Amanda Hodgson, and two anonymous reviewers for comments on the manuscript. The aerial surveys were funded by the Great Barrier Reef Marine Park Authority, Queensland Environmental Protection Agency, The Australian Fish Management Authority, Western Australian Department of Conservation and Land Management, and the Commonwealth Department of Environment.

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Appendix 1. List of Irrawaddy dolphin stranding and museum specimen records in Australian waters. The date given refers to the known date of the stranding or the date the specimen was found and reported, or the date the specimen was registered in a particular museum. Locality is given with reference to named geographical features and as latitude and longitude, although in some circumstances these are only approximations. Institution abbreviations are as follows: AM = Australian Museum, JCU = James Cook University, MTQ = Museum of Tropical Queensland, NMNH = National Museum of National History, MAGNT = Museum and Art Galleries of the Northern Territory, PWCNT = Parks and Wildlife Commission of the Northern Territory, QM = Queensland Museum, QPWS = Queensland Parks and Wildlife Service, and WAM = Western Australian Museum.

Reg. No.	*Date*	*Location*	*Latitude*	*Longitude*	*Institution*	*Reference*
M12359	1-Sep-68	Cairns	17° 00'S	146° 00'E	AM	Sandy Ingleby (pers. comm, 2000)
M33213	6-Dec-97	Daru, PNG	09° 08'S	143° 07'E	AM	Sandy Ingleby (pers. comm, 2000)
JCU1026	11-May-86	Balgal Beach	19° 02'S	146° 25'E	JCU	Jenny Haines (pers. comm., 2000)
JCU1027	21-Jun-86	Saunders Beach	19° 11'S	146° 41'E	JCU	Jenny Haines (pers. comm., 2000)
JCU1031	12-Sep-86	Pallarenda Beach	19° 12'S	146° 47'E	JCU	Jenny Haines (pers. comm., 2000)
JCU1032	14-Sep-86	Ollera Creek	19° 11'S	146° 41'E	JCU	Jenny Haines (pers. comm., 2000)
JCU1034	01-Oct-86	Toolakea Beach	19° 11'S	146° 41'E	JCU	Jenny Haines (pers. comm., 2000)
JCU1039	27-Jul-88	Toolakea Beach	19° 08'S	146° 35'E	JCU	Jenny Haines (pers. comm., 2000)
JCU1042	03-Oct-88	Saunders Beach	19° 11'S	146° 40'E	JCU	Jenny Haines (pers. comm., 2000)
JM11342	Unknown	Townsville	19° 16'S	146° 48'E	MTQ	Arnold and Beasley (pers. comm.,2000)
JM11343	18-Nov-68	Horseshoe Bay, Magnetic Island	19° 07'S	146° 51'E	MTQ	Arnold and Beasley (pers. comm., 2000)
JM4700	23-Sep-69	Pallarenda, Townsville	19° 12'S	146° 46'E	MTQ	Arnold and Beasley (pers. comm., 2000)
JM4704	23-Apr-71	Horseshoe Bay, Magnetic Island	19° 07'S	146° 51'E	MTQ	Arnold and Beasley (pers. comm., 2000)
JM4705	23-Apr-70	Horseshoe Bay, Magnetic Island	19° 07'S	146° 51'E	MTQ	Arnold and Beasley (pers. comm., 2000)
JM4705A	Unknown	Horseshoe Bay, Magnetic Island	19° 07'S	146° 51'E	MTQ	Arnold and Beasley (pers. comm., 2000)
JM4706	23-Apr-70	Horseshoe Bay, Magnetic Island	19° 07'S	146° 51'E	MTQ	Arnold and Beasley (pers. comm., 2000)
JM4706A	23-Apr-70	Horseshoe Bay, Magnetic Island	19° 07'S	146° 51'E	MTQ	Arnold and Beasley (pers. comm., 2000)
JM4707	3-Oct-70	Pallarenda, Townsville	19° 12'S	146° 46'E	MTQ	Arnold and Beasley (pers. comm., 2000)
JM4708	13-Dec-70	Horseshoe Bay, Magnetic Island	19° 07'S	146° 51'E	MTQ	Arnold and Beasley (pers. comm., 2000)
JM4709	23-Jan-71	Horseshoe Bay, Magnetic Island	19° 07'S	146° 51'E	MTQ	Arnold and Beasley (pers. comm., 2000)
JM4712	10-Jun-71	Pallarenda, Townsville	19° 12'S	146° 46'E	MTQ	Arnold and Beasley (pers. comm., 2000)
JM4714	4-Sep-70	Townsville	19° 16'S	146° 48'E	MTQ	Arnold and Beasley (pers. comm., 2000)
JM4720	18-Mar-72	Kissing Point, Townsville	19° 14'S	146° 48'E	MTQ	Arnold and Beasley (pers. comm., 2000)
JM4721	21-Apr-72	Horseshoe Bay, Magnetic Island	19° 07'S	146° 51'E	MTQ	Arnold and Beasley (pers. comm., 2000)
JM4722	18-Aug-74	Pallarenda, Townsville	19° 12'S	146° 46'E	*	Jenny Haines (pers. comm., 2000)
JM4723	18-Aug-74	Pallarenda, Townsville	19° 12'S	146° 46'E	*	Jenny Haines (pers. comm., 2000)
JM4725	18-Aug-74	Pallarenda, Townsville	19° 12'S	146° 46'E	MTQ	Arnold and Beasley (pers. comm., 2000)
JM4726	18-Aug-74	Pallarenda, Townsville	19° 12'S	146° 46'E	MTQ	Arnold and Beasley (pers. comm., 2000)
JM4727	28-Mar-75	The Strand, Townsville	19° 16'S	146° 48'E	MTQ	Arnold and Beasley (pers. comm., 2000)
JM4729	27-Aug-75	Kissing Point, Townsville	19° 14'S	146° 48'E	MTQ	Arnold and Beasley (pers. comm., 2000)
JM4734	30-Jul-76	Pallarenda, Townsville	19° 12'S	146° 46'E	MTQ	Arnold and Beasley (pers. comm., 2000)

Appendix 1. (Continue)

Reg. No.	*Date*	*Location*	*Latitude*	*Longitude*	*Institution*	*Reference*
JM4735	10-Sep-76	Rowe's Bay,Townsville	19° 13'S	146° 47'E	MTQ	Arnold and Beasley (pers. comm., 2000)
JM4736	4-Oct-76	Rowe's Bay,Townsville	19° 13'S	146° 47'E	MTQ	Arnold and Beasley (pers. comm., 2000)
JM4739	9-Aug-84	Ross River mouth	19° 16'S	146° 50'E	*	Jenny Haines (pers. comm., 2000)
JM4740	30-Sep-84	Toolakea Beach, Townsville	19° 09'S	146° 35'E	MTQ	Arnold and Beasley (pers. comm., 2000)
JM4741	10-Jun-71	Pallarenda, Townsville	19° 12'S	146° 46'E	*	Jenny Haines (pers. comm., 2000)
JM4751	Unknown	Townsville	19° 16'S	146° 48'E	MTQ	Arnold and Beasley (pers. comm., 2000)
JM4752	Unknown	Townsville	19° 16'S	146° 48'E	MTQ	Arnold and Beasley (pers. comm., 2000)
MM1039	Unknown	Townsville	19° 16'S	146° 48'E	MTQ	Arnold and Beasley (pers. comm., 2000)
MM92	24-Aug-75	Kissing Point, Townsville	19° 14'S	146° 48'E	MTQ	Arnold and Beasley (pers. comm., 2000)
Unregistered	Unknown	Townsville	19° 16'S	146° 48'E	MTQ	Arnold and Beasley (pers. comm., 2000)
Unregistered	Unknown	Townsville	19° 16'S	146° 48'E	MTQ	Arnold and Beasley (pers. comm., 2000)
284429	16-Jul-48	Melville Bay, NT	12° 00'S	131° 00'E	NMNH	Beasley (pers. comm., 2000)
284430	16-Jul-48	Melville Bay, NT	12° 00'S	131° 00'E	NMNH	Beasley (pers. comm., 2000)
NTMU249	19-Oct-83	Melville Island, off Point Jaheel, Northern Territory	11° 13'S	131° 20'E	MAGNT	Paul Horner (pers. comm., 2000)
NTMU5079	Unknown	Unknown			MAGNT	Paul Horner (pers. comm., 2000)
NTMU532	1985	Unknown			MAGNT	Paul Horner (pers. comm., 2000)
N/A	12-Jun-92	Fog Bay, 70 km southwest of Darwin	12° 50'S	130° 31'E	PWCNT	Chatto & Warneke (2000)
N/A	Aug-97	Indian Island, Bynoe Harbour	12° 37'S	130° 31'E	PWCNT	Chatto & Warneke (2000)
N/A	27-May-99	Northeast side of Is. of Woodah, Gulf of Carpentaria	13° 22'S	136° 08'E	PWCNT	Chatto & Warneke (2000)
N/A	01-Oct-99	Dundee Beach, Fog Bay	12° 46'S	130° 22'E	PWCNT	Chatto & Warneke (2000)
JM10574	18-Jul-94	Moore PK Beach, Bundaberg	24° 52'S	152° 21'E	QM	Stephen Van Dyck (pers. comm., 2000)
JM11976	20-Jul-97	Karavana Downs, Brisbane River	27° 32'S	152° 49'E	QM	Stephen Van Dyck (pers. comm., 2000)
JM1339	Unknown	Unknown			QM	Stephen Van Dyck (pers. comm., 2000)
JM14263	12-Jul-66	Cleveland Bay, Townsville	19° 13'S	146° 55'E	QM	Stephen Van Dyck (pers. comm., 2000)
JM4937	22-Jan-85	Main Beach, Cape Hillsborough	20° 55'S	149° 00'E	QM	Stephen Van Dyck (pers. comm, 2000)
JM511	27-Sep-74	Harbour Beach, Mackcay	21° 09'S	149° 11'E	QM	Stephen Van Dyck (pers. comm, 2000)
W1088	16-Sep-99	Mulambin Beach, Yeppoon	23° 12'S	150° 48'E	QPWS	Jenny Haines (pers. comm., 2000)
W117	15-Jul-95	Ellis Beach, Cairns	16° 43'S	145° 39'E	QPWS	Jenny Haines (pers. comm., 2000)
W118	15-Jul-95	Ellis Beach, Cairns	16° 43'S	145° 39'E	QPWS	Jenny Haines (pers. comm., 2000)
W120	22-Sep-95	Ellis Beach, Cairns	16° 43'S	145° 39'E	QPWS	Jenny Haines (pers. comm., 2000)
W123	20-Jul-96	Ellis Beach, Cairns	16° 43'S	145° 39'E	QPWS	Jenny Haines (pers. comm., 2000)

Appendix 1. (Continue)

Reg. No.	*Date*	*Location*	*Latitude*	*Longitude*	*Institution*	*Reference*
W143	31-Aug-92	Bucasia, Mackay	21° 02'S	149° 10'E	QPWS	Jenny Haines (pers. comm., 2000)
W22	05-Aug-96	Black's Beach	21° 03'S	149° 11'E	QPWS	Jenny Haines (pers. comm., 2000)
W231	15-May-89	Horseshoe Bay	19° 07'S	146° 51'E	QPWS	Jenny Haines (pers. comm., 2000)
W237	10-Oct-90	Horseshoe Bay	19° 07'S	146° 51'E	QPWS	Jenny Haines (pers. comm., 2000)
W25	13-Aug-96	Williamson's Beach	20° 59'S	149° 06'E	QPWS	Jenny Haines (pers. comm., 2000)
W539	29-Apr-85	Pallarenda Beach	19° 12'S	146° 46'E	QPWS	Jenny Haines (pers. comm., 2000)
W540	20-May-85	Saunders Beach	19° 11'S	146° 39'E	QPWS	Jenny Haines (pers. comm., 2000)
W563	18-Jun-87	Saunders Beach	19° 11'S	146° 40'E	QPWS	Jenny Haines (pers. comm., 2000)
W57	22-Jul-91	Ellis Beach, Cairns	16° 43'S	145° 39'E	QPWS	Jenny Haines (pers. comm., 2000)
W907	30-Oct-97	O'Connel River, 1km upstream	20° 33'S	148° 39'E	QPWS	Jenny Haines (pers. comm., 2000)
W908	30-Oct-97	O'Connel River	20° 35'S	148° 40'E	QPWS	Jenny Haines (pers. comm., 2000)
W916	30-Jul-97	Sea Hill, 500m NE.Lighthouse	23° 29'S	150° 59'E	QPWS	Jenny Haines (pers. comm., 2000)
W971	17-Mar-98	Pallarenda, 3 Mile Creek	19° 13'S	146° 46'E	QPWS	Jenny Haines (pers. comm., 2000)
W989	29-Sep-98	O'connel River, Thomson Creek	20° 23'S	148° 40'E	QPWS	Jenny Haines (pers. comm., 2000)
M23242	25-Jun-65	Crab Creek Broome	18° 00'S	122° 24'E	WAM	Norah Cooper (pers comm., 2000)
M23243	25-Jun-65	Crab Creek Broome	18° 00'S	122° 24'E	WAM	Norah Cooper (pers comm., 2000)
M23244	14-May-65	Cable Beach, Broome	17° 55'S	122° 15'E	WAM	Norah Cooper (pers comm., 2000)
M23301	20-Oct-85	Town Beach, Broome	17° 58'S	122° 14'E	WAM	Norah Cooper (pers comm., 2000)
M52387	3-Mar-84	Derby	17° 19'S	123° 38'E	WAM	Norah Cooper (pers comm., 2000)

* These specimens are not found at MTQ or QM, as their registration numbers indicates, however they are reported in the QPWS stranding database.

Appendix 2. List of vessel-sighting records of Irrawaddy dolphins in Australian waters.

Date	*Location*	*Latitude (S)*	*Longitude (E)*	*Group. Size*	*Source*
1995	Hinchinbrook Channel	18° 18'S	146° 04'E	10	Preen
17-Feb-98	Tip of Cape Bowling Green	19° 18'S	147° 23'E	4	QPWS
26-Mar-98	Cleveland Bay	19° 17'S	146° 57'E	5	Preen
26-Mar-98	Cleveland Bay	19° 14'S	146° 52'E	6	Preen
16-Apr-98	Cleveland Bay	19° 14'S	146° 50'E	2	Preen
28-Sep-98	Cleveland Bay	19° 14'S	146° 50'E	7	QPWS
21-Aug-99	North east Bay Palm Island	18° 44'S	146° 41'E	1	QPWS
10-Nov-99	Townsville Port Channel	19° 14'S	146° 50'E	5	QPWS
20-Jan-00	Mouth of Black River	19° 10'S	146° 39'E	4	QPWS
20-Jan-00	Off Bushland Beach	19° 11'S	146° 41'E	5	QPWS

Appendix 3. a) List of aerial surveys reviewed in the manuscript.

Month-Year	*Survey Region*	*Survey Methodology*	*Study Area (km^2)*	*Area Sampled (km^2)*	*Sampling intensity*	*No. of Sightings*		*Reference*
						Certain	Uncertain	
Sep-1986	Dunk Island-Cape Cleveland	Strip Transect	5480	597	10.9	1	0	Marsh and Saalfeld, 1992
Oct-1986	Repulse Bay-Bustard Head	Strip Transect	16090	1609	10	3	2	Marsh and Saalfeld, 1992
Oct-1987	Dunk Island-Cape Cleveland	Strip Transect	5480	625	11.4	3	0	Marsh and Saalfeld, 1992
Sep-Oct-1987	Cape Cleveland-Repulse Bay	Strip Transect	6298	768	12.2	0	1	Marsh and Saalfeld, 1992
Jul-1989	Exmouth	Strip Transect	3180	293	9.2	0	0	Preen et al., 1995
Jul-1989	Ningaloo	Strip Transect	555	46	8.3	0	0	Preen et al., 1995
Jul-1989	Shark Bay	Strip Transect	14906	1295	8.6	0		Preen et al., 1995
Nov-Dec-1990	Hunter Point-Cape Bedford	Strip Transect	31288	2847	9.1	0	0	Marsh et al., 1990
Dec-1991	Mornington Island	Strip Transect	8848	726	8.2	0	0	Marsh and Lawler, 1993
Nov-Dec-1991	Torres Strait	Strip Transect	30560	1772	5.8	0	0	Marsh and Lawler 1992
Nov-Dec-1992	Cape Bedford-Bustard Head	Strip Transect	39396	3978	10.1	0	0	Unpublished
Nov-Dec-1994	Dunk Island-Bustard Head	Strip Transect	28564	3113	10.9	1	0	Marsh et al., 1996
Nov-Dec-1994	Karumba	Strip Transect	2715	236	8.7	0	0	Marsh et al., 1995
Jun-1994	Exmouth	Strip Transect	3180	293	9.2	0	0	Preen et al., 1995
Jun-1994	Ningaloo	Strip Transect	869	77	8.9	0	0	Preen et al., 1995
Jun-1994	Shark Bay	Strip Transect	14906	1295	8.6	0	0	Preen et al., 1995
Dec-1994	Torres Strait	Strip Transect	4340	405	9.3	0	0	Marsh et al., 1994
Nov-Dec-1995	Hunter Point-Cape Bedford	Strip Transect	25800	2528	9.8	3	1	Marsh and Corkeron, 1996
Apr-May-July-Sep-Aug-1996	Shoalwater Bay	Shoreline	1185	1586 km*		0	0	Preen, 1999b
Jul-Dec-1996	Townsville-Cardwell	Strip Transect-Shoreline	888	402 km*		2	0	Unpublished

Appendix 3a. (Continue)

Month-Year	*Survey Region*	*Survey Methodology*	*Study Area (km^2)*	*Area Sampled (km^2)*	*Sampling intensity*	*No. of Sightings*		*Reference*
						Certain	Uncertain	
Aug-1997	Shoalwater Bay	Strip Transect	1185	356	30	0	0	Preen, 1999b
Dec-1997	Eastern Gulf of Carpentaria	Strip Transect	33026	1995	6.0	3	0	Marsh et al., 1998
Apr-May-July-Aug-Oct-Dec-1997	Townsville-Cardwell	Strip Transect-Shoreline	888	243	27.4	12	0	Preen, 1999a
Feb-Mar-Apr-1998	Townsville-Cardwell	Strip Transect-Shoreline	888	228	25.7	1	0	Preen, 1999a

* Total linear kilometres of shoreline surveys. These surveys did not aim to cover all the study area, just the areas assumed to be the best habitat.

Appendix 3. b) List of aerial survey sighting records of Irrawaddy dolphins classified as "certain" in Australian waters.

Year	*Survey Area*	*Latitude*	*Longitude*	*Group Size*
86 (Nov.)	Repulse Bay to Bustard Head	22° 00'S	149° 40'E	1
86 (Oct.)	Repulse Bay-Bustard Head	21° 57'S	149° 50'E	5
86 (Oct.)	Repulse Bay-Bustard Head	21° 22'S	149° 35'E	2
86 (Sep.)	Dunk Island-Cape Cleveland	18° 08'S	146° 10'E	2
87 (Sept.)	Dunk Island-Cape Cleveland	19° 42'S	147° 42'E	1
87 (Sept.)	Dunk Island-Cape Cleveland	18° 06'S	146° 03'E	1
87 (Sept.)	Dunk Island-Cape Cleveland	19° 09'S	146° 41'E	1
94 (Nov.)	Dunk Island-Bustard Head	19° 35'S	147° 44'E	5
95 (Nov.)	Hunter Point-Cape Bedford	14° 16'S	144° 47'E	11
95 (Nov.)	Hunter Point-Cape Bedford	14° 08'S	143° 58'E	1
95 (Nov.)	Hunter Point-Cape Bedford	14° 08'S	144° 36'E	1
96 (Dec.)	Townsville-Cardwell	19° 23'S	147° 24'E	6
96 (Jul.)	Townsville-Cardwell	19° 06'S	146° 33'E	12
97 (Apr.)	Townsville-Cardwell	19° 10'S	146° 46'E	9
97 (Aug.)	Townsville-Cardwell	18° 59'S	146° 23'E	8
97 (Aug.)	Townsville-Cardwell	18° 58'S	146° 22'E	7
97 (Aug.)	Townsville-Cardwell	18° 55'S	146° 20'E	10
97 (Aug.)	Townsville-Cardwell	18° 15'S	146° 02'E	10
97 (Aug.)	Townsville-Cardwell	18° 11'S	146° 13'E	8
97 (Dec.)	Eastern Gulf of Carpentaria	12° 00'S	141° 54'E	2
97 (Dec.)	Mornington	17° 25'S	140° 43'E	1
97 (Dec.)	Mornington	16° 42'S	138° 22'E	7
97 (Jul.)	Townsville-Cardwell	19° 08'S	146° 35'E	10
97 (Oct.)	Townsville-Cardwell	19° 10'S	146° 40'E	10
97 (Oct.)	Townsville-Cardwell	18° 15'S	146° 03'E	2
97(Dec.)	Townsville-Cardwell	19° 09'S	146° 38'E	3
97(Dec.)	Townsville-Cardwell	19° 06'S	146° 30'E	4
97(May)	Townsville-Cardwell	18° 17'S	146° 04'E	14
98 (Apr.)	Townsville-Cardwell	18° 44'S	146° 19'E	3

Appendix 4. Equations used to calculate the exact sighting location of Irrawaddy dolphins from raw data of past aerial surveys.

$$l = (t_2 - t_0)*S \quad (1)$$
$$d = (E - W)/l \quad (2)$$
$$D = (t_1 - t_0)*S \quad (3)$$
$$L = W + D*d \quad (4)$$
$$= E - D*d \quad (5)$$

Where:

- l = length of a transect (km)
- t_0 = start time of an observation (decimal minutes)
- t_1 = time of Irrwaddy dolphin sighting (decimal minutes)
- t_2 = end time of an observation (decimal minutes)
- E = the longitude of the eastern end of a transect (decimal degree)
- W = the longitude of the western end of a transect (decimal degree)
- S = flight speed of an aircraft (km/min)
- D = distance of a sighting location from the start point of a transect (km)
- d = degrees of longitude per a km on a transect (decimal degree/km)
- L = longitude of sighting location