Beaked whale strandings on the coast of Australia in comparison to those of other cetaceans

L.J. HAMILTON AND K. LINDSAY

Defence Science and Technology Organisation (DSTO), NICTA Building, 13 Garden Street, Eveleigh, NSW 2015 Australia

Contact e-mail: les.hamilton@dsto.defence.gov.au

ABSTRACT

Beaked whale (Ziphiidae) strandings on the coast of Australia are examined in comparison to five other odontocete (toothed whale) species and two mysticetes (baleen whales) representative of non-Ziphiids found stranded in Australian waters. Ninety percent of reported beaked whale strandings involve a single animal. Seven beaked whale stranding events of three or more individuals have been recorded from 1871 to 2010, with a maximum in any event of 6. The five non-Ziphiid odontocetes had maximum numbers in a stranding of 13, 51, 65, 200, and 250, and a combined total of 66 events with 10+ in a stranding. The mysticetes had almost exclusively single strandings. Similar trends for the Ziphiids and other cetaceans are generally observed worldwide, although larger numbers of Ziphiids have stranded elsewhere. Continental scale geographical stranding patterns are similar for the Ziphiids, the five non-Ziphiid odontocetes, and the two mysticetes, although not for the same reasons. Reported strandings predominantly occurred around the southern half of Australia south of 20°S. On average around three times as many beaked whale stranding events per month occurred for the period January to April than for July to December. The monthly trend for beaked whale strandings follows the seasonal cycle of sea temperatures, indicating a relation to oceanic phenomena, rather than to the often invoked effect of increased observer effort in months with warmer air temperatures. Some single and dual beaked whale strandings which include a female may be related to use of shallow sheltered waters for calving and subsequent resting.

KEYWORDS: BEAKED WHALE; STRANDINGS; AUSTRALASIA

INTRODUCTION

This paper examines spatial and temporal characteristics of strandings of beaked whales around Australia (Fig. 1). Beaked whales are medium sized marine mammals of about 4 to 13m length, belonging to the order Cetacea, suborder Odontoceti (the toothed whales), and family Ziphiidae. Beaked whales constitute one-third of all species of small cetacean in the Australian region, but very little is known of their numbers, biology, or conservation status (Ross, 2006). However, in the 'Action Plan For Australian Cetaceans', Bannister *et al.* (1996, pp.40–41) have provided a synopsis of the general distribution of beaked whales around Australia in relation to habitat. The diet for some species in other world areas is composed of squid, fish, and occasional crustaceans, apparently obtained from on or near deep seabeds associated with canyons and slopes (MacLeod *et al.*, 2003). Blainville's beaked whales (*Mesoplodon densirostris*) have been observed to dive up to 1,200m for prey, and Cuvier's beaked whales (*Ziphius cavirostris*) up to 1,900m (Tyack *et al.*, 2006). Some non-Ziphiids are also deep divers, for example a sperm whale dive to 1,169m has been recorded (Miller *et al.*, 2004). However, Blainville's and Cuvier's beaked whales appear to be the deepest known divers of all marine mammals.

In recent years, beaked whales have received an increasing amount of attention from the research community, conservation groups and defence organisations. This focus has arisen because of mass strandings of beaked whales in some widely separated Northern Hemisphere areas being causally linked with use of naval active sonar, particularly for frequencies 1–10 kHz (Frantzis, 2004; Jepson *et al.*, 2003; Johnson *et al.*, 2004; Piantadosi and Thalmann, 2003; Rommel *et al.*, 2006). It is a matter of concern to the Royal Australian Navy (RAN) that their activities should not disturb marine mammals. Policy directives have been derived with community consultation (The Maritime Activities Environmental Management Plan) specifically aimed at minimizing or curtailing the use of active sonar when marine mammals are likely to be present (Cole, 2008). The RAN have commissioned passive acoustic surveys prior to, during, and after naval exercises in the Coral Sea (Cato *et al.*, 2009) in order to monitor and avoid marine mammals, particularly beaked whales. Passive acoustics can detect beaked whales without disturbing them by listening to and identifying the stereotyped chirps they make during feeding dives (e.g. Hamilton and Cleary, 2010). To make informed decisions on possible relations between strandings of beaked whales and anthropogenic activities (no occurrences of which have been observed about Australia; Commonwealth of Australia, 2008), information is also needed on factors such as stranding rates, and whether or not strandings have geographical or seasonal trends. This information is currently unknown, and is the focus of the present paper.

Related strandings of two or more whales, excluding mother-calf pairs, occur infrequently, and so are regarded as anomalous. Consequently so-called mass strandings of cetaceans can involve as few as two animals which beach some time and distance apart. For example D'Amico *et al.* (2009) define a 'mass' stranding as two or more cetaceans beaching within six days and 74km, excluding mother-calf pairs. D'Amico *et al.* (2009) quote an average worldwide mass stranding rate for beaked whales of 2.3 events per year for 1950 to 2004, and four per year for 1985 to 2004. Ross (2006) states that false killer whales (*Pseudorca crassidens*) are 'prone' to mass stranding on Australian coasts based on an average of one such event every 2.5 years. These numerically low rates of occurrence set the context for any analysis of strandings.

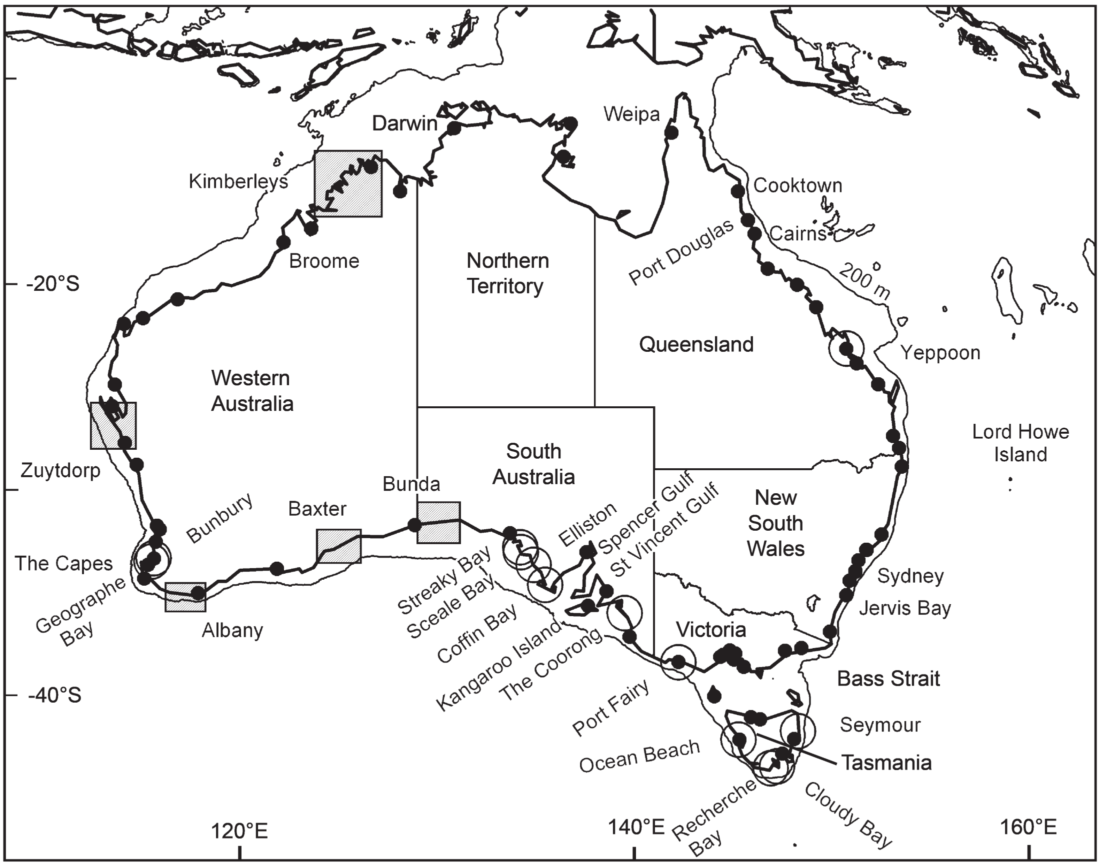

Fig. 1. The Australian coastline, states, and selected place names and population centres. Sea cliffs and rocky areas are outlined with rectangles.

In view of the infrequency of occurrence of mass strandings, this paper examines the beaked whale stranding record for the entire Australian continent, including single strandings. The authors are unaware of previous work directed specifically to beaked whale strandings around Australia as a whole. Some details of beaked whale strandings around Australia were compiled by Kemper and Ling (1991) in an examination of cetacean strandings in South Australia, and D'Amico *et al.* (2009) included Australian beaked whale mass strandings in a global examination. A true picture of beaked whale stranding behaviour around Australia can only be gained when the whole continent is examined and when the proportion of single to mass strandings is known.

The primary questions in the study addressed in this paper are as follows: Are there spatial or temporal patterns to beaked whale strandings? Do the various beaked whale species have different stranding patterns? How many beaked whales are typically involved in a stranding? Noting that an examination of the stranding patterns of beaked whales in isolation may not be particularly meaningful, how do the stranding patterns of beaked whales compare to those of other cetaceans?

One topic is of special interest. In a companion analysis, Hamilton and Lindsay (2014) found that sites of non-Ziphiid odontocete mass strandings of 10 or more individuals were strongly associated with sandy bays (this applied to at least 34 of the 36 sites and 64 of the 66 events recorded over 143 years), particularly those with headland-bay character. A description of headland-bays is given here in 'Materials and Methods'. Hamilton and Lindsay (2014) did not specifically examine beaked whale strandings because all such events involved less than 10 individuals. A further question is thus: Do beaked whales also typically mass strand in headland-bays?

MATERIALS AND METHODS

Database of stranding records

Three hundred and thirty-one beaked whale (Ziphiid) stranding records and 386 stranding records representative of non-Ziphiids were compiled into the authors' database. Attributes recorded were Species, Season, Month, Year, Australian State, Locality name, Latitude, Longitude, Position quality indicator, Number stranded, Status (live – found alive, or active stranding observed; passive – carcass found; unknown/uncertain – skeletal material, not recorded, or doubt as to the veracity of the status), General observations (e.g. sex, age, evidence of shark attack, disease), and Source of the record, including the authority for the identification.

Beaked whale stranding reports were obtained from the Australian, South Australian, and Queensland Museums, the Tasmanian Museum and Art Gallery, and OZCAM (Online Zoological Collection of Australian Museums). Other sources were the Commonwealth of Australia strandings database[1], research papers and annual reports of the

[1]Commonwealth of Australia. 2010. National Whale and Dolphin Sightings and Strandings Database. Department of Environment, Water, Heritage and the Arts. [Retrieved 11 February, 2010 from *http://data.aad.gov.au/aadc/whales/*]

International Whaling Commission (IWC). In addition, if judged to be of sufficient quality, data from 'non-scientific' sources such as press and internet reports were used; great care was taken to verify the latter sources using cross-checks, photographs and noting the authority for the identification. Photographs of strandings from internet and press reports sometimes enable very good positions to be obtained. However, in one case a photograph of stranded odontocetes from 2008 was reused for a stranding at the same site in 2011. Australian stranding records for the selected species in the authors' database date back to year 1868 for the sperm whale and 1871 for beaked whales and extend up to 2010.

Active or live strandings are of primary relevance for analysing causes of beachings related to cetacean behaviour. However, coupling of the low stranding rate of cetaceans with the need for strandings to be noted by human observers provides only a limited database. Carcass strandings and strandings of unknown status may be valuable in reinforcing the general geographical patterns observed for live strandings. Fresh carcass strandings are also useful for examinations of seasonality.

The quality of positional information associated with strandings is uneven, as is the spatial and temporal sampling. Analyses must be made with some circumspection, and only very clear trends, if any exist, are likely to have meaning. For example, we did not attempt to read too much regarding long term variation into records with irregular time series, but seasonality was sometimes very obvious for composite data. Geographical co-ordinates in the publicly available Commonwealth of Australia database are mostly too inaccurate for site specific analyses. Latitudes and longitudes are rounded to the nearest half-degree. This means that strandings up to 1.4 degrees (155km) removed from each other can be assigned the same position. Some positions are more than 3 degrees from the actual stranding site. Co-ordinates were assigned for specifically named sites such as beaches and other locations from RAN Hydrographic Office bathymetry charts (WGS84 datum) but in some cases the position is not known accurately enough for site specific analyses.

A confounding factor in strandings is the number of cetaceans killed intentionally or unintentionally by humans. At least 25% of recorded cetacean mortalities in South Australia for 1985–2000 were directly human caused (Kemper *et al.*, 2005) although beaked whales did not appear in this category. Entanglements and captures were excluded from the database. The quality control and data gathering methods used makes the database probably the most comprehensive and verified Australian beaked whale stranding record compiled to date.

Beaked whale stranding records

The database contains 331 records (single and mass strandings) for 12 beaked whale species and an 'Unknown' species category. A total of 308 records were identified to species level (Table 1). For descriptions and behavioural details of the beaked whale species in Table 1, see Culik (2004).

Non-beaked whale stranding records

Seven non-Ziphiids were included as representative of the non-beaked whale species found stranded in Australian waters. Both suborders of Cetacea (Odontoceti or toothed whales and Mysticeti or baleen whales) were included to provide balanced sampling. Two of the seven were mysticetes of the family Balaenopteridae, namely the humpback whale (*Megaptera novaeangliae*) and the Antarctic minke whale (*Balaenoptera bonaerensis*). The other five were odontocetes belonging to two separate families, Physeteridae for which the sperm whale (*Physeter macrocephalus*) is the sole member, and Delphinidae including the long-finned pilot whale (*Globicephala melas*), killer whale (*Orcinus orca*), false killer whale (*Pseudorca crassidens*), and melon-headed whale (*Peponocephala electra*). All non-beaked whale stranding records were identified to species level. These included 143 sperm whale records, 112 long-finned pilot whale records, 58 Antarctic minke whale records and 48 humpback whale records (a total of 361). Only mass strandings were included in the database for the false killer whale (20 events), melon-headed whale (3 events), and killer whale (2 events). The non-Ziphiid Odontoceti (and Mysticeti) species were broadly selected as having sufficient records for analysis, and as having different mature adult size, for example, sperm whale/long-finned pilot whale for the odontocetes, and humpback/minke for the mysticetes. This was to examine possible differences in stranding behaviour caused by size to factors such as agility in shallower waters, habitat/feeding behaviour, and efficiency and acoustic frequency of vocalisations.

Table 1

Beaked whale species and numbers in stranding events around Australia for 1871 to 2010 ordered by total number of strandings.

Beaked whale species	Scientific name	Single	Dual	Triple	Four	Six	Totals
Strap-toothed beaked whale	*Mesoplodon layardii*	94	10	3	–	–	107
Gray's beaked whale	*Mesoplodon grayi*	57	8	1	1	1	68
Cuvier's beaked whale	*Ziphius cavirostris*	38	2	–	–	–	40
Blainville's beaked whale	*Mesoplodon densirostris*	21	3	–	–	–	24
Unknown	–	21	2	–	–	–	23
Andrew's beaked whale	*Mesoplodon bowdoini*	19	1	–	–	–	20
Southern bottlenose whale	*Hyperoodon planifrons*	19	–	–	–	–	19
Hector's beaked whale	*Mesoplodon hectori*	8	2	–	–	–	10
Arnoux's beaked whale	*Berardius arnuxii*	7	–	–	–	–	7
Ginkgo-toothed beaked whale	*Mesoplodon ginkgodens*	5	–	–	–	–	5
Shepherd's beaked whale	*Tasmacetus shepherdi*	3	–	1	–	–	4
True's beaked whale	*Mesoplodon mirus*	3	–	–	–	–	3
Longman's beaked whale	*Indopacetus pacificus*	1	–	–	–	–	1
Total		**298**	**28**	**5**	**1**	**1**	**331**

Headland-bays

A headland-bay is a geomorphological coastal unit for which wave and swell action form a bay downswell of the headland with a characteristic log-spiral shape (Fig. 2). Many headland-bays have a headland at both ends, not a single headland. Bay width was measured from headland to beach end for the single headland case, and headland to headland when two were present. Bay indentation distance was measured as the maximum value to shore perpendicular to the line specifying the bay width. Hamilton and Lindsay (2014) noted that the more classically shaped headland-bays have width to indentation ratio greater than 2, with indented bays having ratio less than 2, allowing an initial differentiation of bay types through examination of coastal charts. Indented bays can also have significant headland-bay character. For these cases the log-spiral shape is present in the planform, but a second headland, usually secondary in comparison to the other, introduces indentation on the other side of the bay. Australian headland-bays typically have fine sandy beaches and offhsore seabed slopes of less than 0.5° (Hamilton and Lindsay, 2014).

RESULTS

Geographical stranding patterns

Broadscale geographical patterns for all species examined

The continental scale geographical distribution of all Ziphiid and non-Ziphiid strandings shows a simple pattern (Fig. 3a). Reported strandings occur predominantly in the southern half of the Australian continent south of 20°S, including all round Tasmania. The stranding patterns are generally the same for whales thought to use echolocation for navigation (i.e. the beaked whales, Fig. 3b, and the five non-Ziphiid odontocete species, Fig. 3c), and those which may not (the two mysticetes, Fig. 3d). Beaked whale strandings plotted by status (live/active, carcase/passive or unknown) (Fig. 4) show the same stranding patterns as Fig. 3. More strandings for all Ziphiid and non-Ziphiid species are reported for southwestern Australia, mid to eastern South Australia, and on the east coast of Tasmania, than elsewhere. There is only one reported beaked whale stranding between 120.12–130.3°E, 32–34°S along the high-cliffed rock coast of southern Australia. North of a stranding at 17.8°S, 122°E near Broome, Western Australia the only recorded strandings for the selected species are on the northernmost shoreline of the Northern Territory, with six events noted between 130.3°E to 136°E, these being three beaked whales, two sperm whales (Chatto and Warneke, 2000, have four), and a humpback whale. Strandings are also recorded on islands in Bass Strait, and on oceanic islands remote from Australia, namely Lord Howe, Heard (53°S, 72°30'E), and Macquarie Islands (54.62°S, 158.861°E).

Strandings of individual Ziphiid species are charted in Fig. 5, and strandings of the five non-Ziphiid odontocetes in Fig. 6. There are some regional differences between strandings of beaked whale species, although they are not marked. Blainville's beaked whale strandings mostly occur on the east coast; Cuvier's mostly strand about Tasmania and the Capes (Cape Naturaliste and Cape Leeuwin, Western Australia); and southern bottlenose beaked whales strand mostly in South Australia. Gray's and strap-toothed beaked whales have a wider stranding distribution than other Ziphiids, resembling those of the sperm whale and long-finned pilot whale.

Beaked whale stranding locations

The object of this section is to examine beaked whale stranding locations to see if they have any characteristics in common, and to see if beaked whales strand at the same type

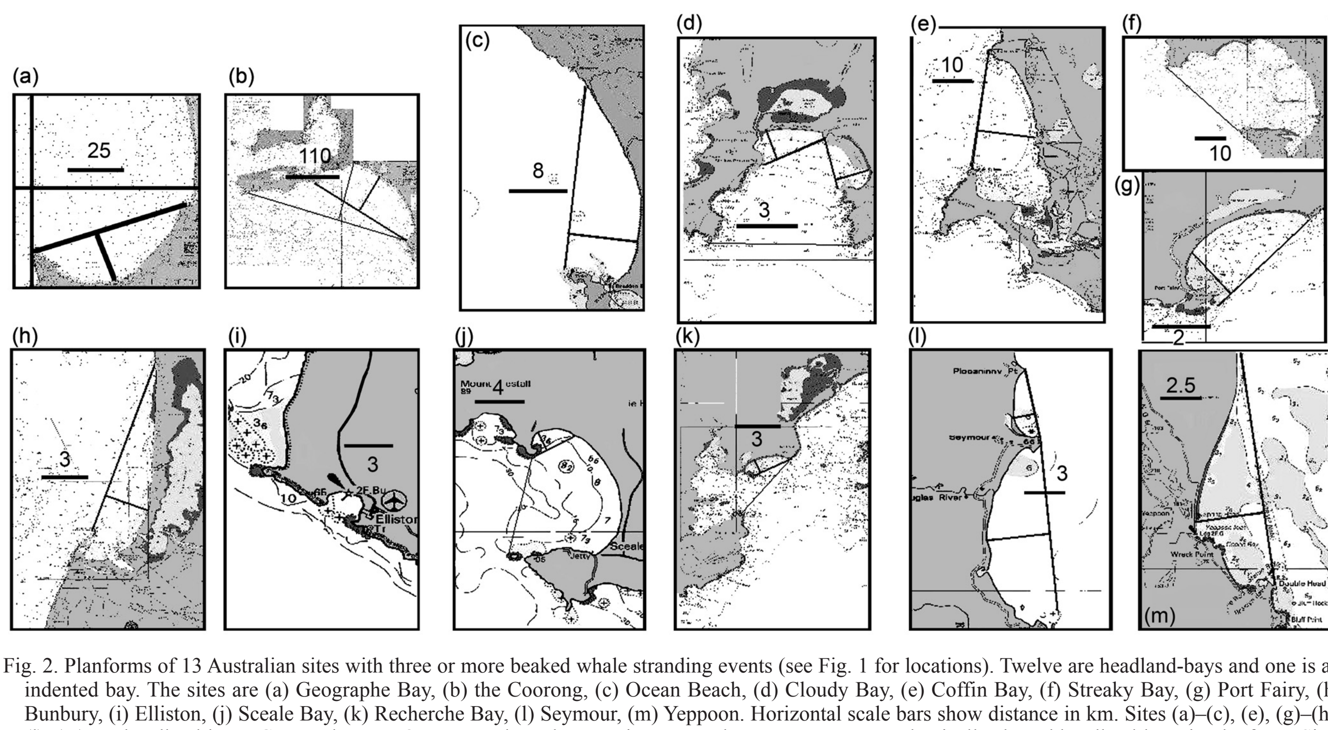

Fig. 2. Planforms of 13 Australian sites with three or more beaked whale stranding events (see Fig. 1 for locations). Twelve are headland-bays and one is an indented bay. The sites are (a) Geographe Bay, (b) the Coorong, (c) Ocean Beach, (d) Cloudy Bay, (e) Coffin Bay, (f) Streaky Bay, (g) Port Fairy, (h) Bunbury, (i) Elliston, (j) Sceale Bay, (k) Recherche Bay, (l) Seymour, (m) Yeppoon. Horizontal scale bars show distance in km. Sites (a)–(c), (e), (g)–(h), (l)–(m) are headland-bays. Geographe Bay, Ocean Beach, and Port Fairy approach prototype or more classically shaped headland-bays in planform. Sites (d)(f)(j)(k) are indented bays with headland-bay character or interior headland-bays. Site (i) is an indented bay. Straight lines drawn on the planforms define bay width and indentation distance perpendicular to bay width.

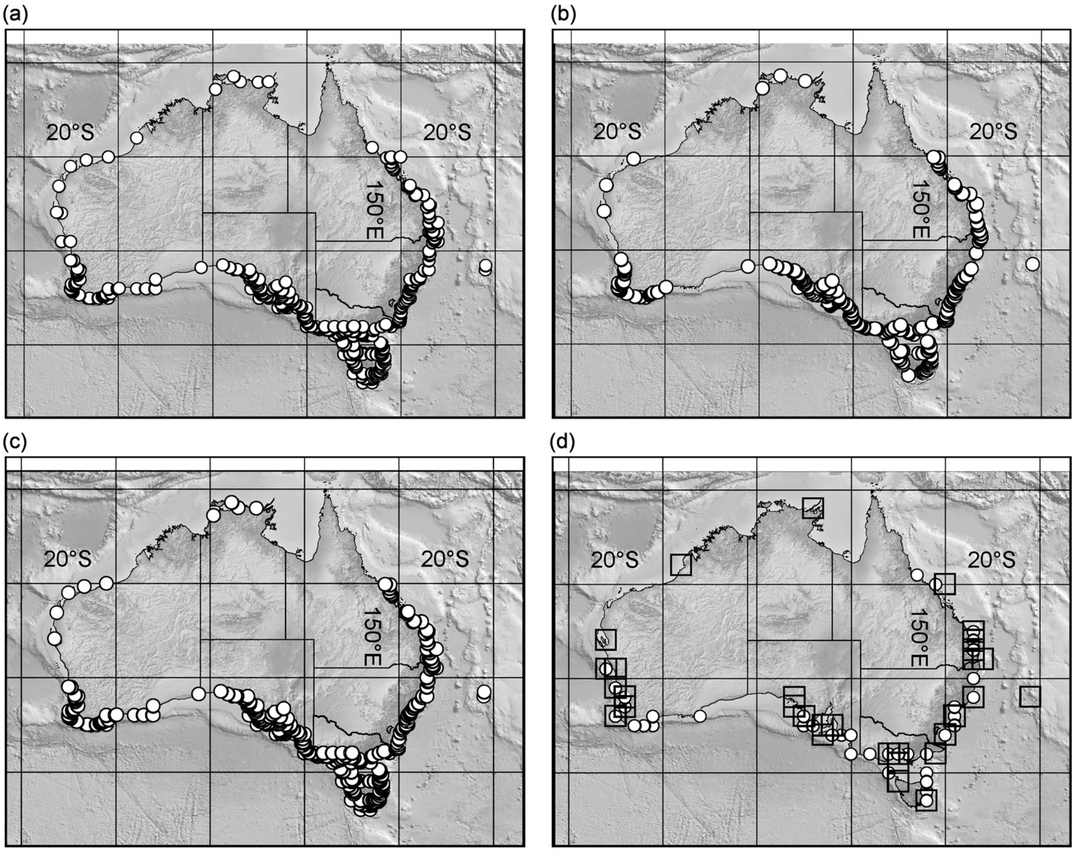

Fig. 3. Locations of strandings (live, passive, and unknown status) of beaked whales (Ziphiidae), and of seven selected non-Ziphiid species (five odontocete species and two mysticete species) on the Australian coastline. Bathymetry is from Kilgour and Hatch (2002).
(a) Combined strandings of all species (717 reports in total).
(b) Beaked whale strandings (331 in total).
(c) Strandings of five non-Ziphiid odontocetes (280 in total). Single and mass strandings for the long-finned pilot and sperm whale, and mass strandings only for the false killer whale, killer whale, and melon-headed whale.
(d) Mysticete strandings (106 in total). Antarctic minke whale (□), humpack whale (○).

of locations as other cetaceans. Sites with more than one stranding event are more likely to provide reliable information of this kind. The location of many sites are not well known, and this hampers spatial analysis. Only seven beaked whale stranding events have three or more animals in a stranding (Table 1). Six have good positional information and all are in bays (Fig. 7). Five are in headland-bays (Mandurah, Geographe Bay (2 events) and Denmark in Western Australia; and Victor Harbour in South Australia), and one is in an indented bay with interior headland-bays (Cloudy Bay, Tasmania). Of 28 dual strandings (mother-calf pairs included), half are located in bays (two are indented headland-bays, and 12 are more classically shaped headland-bays). The remainder are not well enough located for site specific analyses, but it appears that three are probably in a headland-bay, and seven are not or probably not in a headland-bay. Of the 28 dual strandings, 3 are not a mother-calf pair, 6 are a mother-calf pair, 11 include a female, and 8 have no details on age or sex. Those with a female or no details on sex could be mother-calf pairs, so that 20 to 90% of cases might not be defined as mass strandings.

There were 45 sites with two or more beaked whale stranding events, including single strandings, accounting for 124 of all 331 (37%) Ziphiid stranding events. Thirteen of the 45 sites (29%) had at least one known live beaked whale stranding event. Seventeen of the 45 (38%) also had strandings of non-Ziphiid odontocetes, and 10 of these 17 also had mysticete strandings. Three of the 45 (17%) also had a single stranding of a mysticete and no non-Ziphiid odontocete strandings. The 45 sites include larger coastline areas with a common geomorphology such as Geographe Bay (Western Australia) and Cloudy Bay (Tasmania, Fig. 2), rather than being specific beaches or sites. At least 28 of 45 (62%) are bays of some type, including 25 headland-bays or bays with headland-bay character in planform, and 3 indented bays. Five are capes, 4 are points, 1 is a port, and 6 have no indication of coastal type. It is not known if the strandings on capes and points are associated with headland-bays, because no indication is given on which side of these features the strandings occurred.

Thirteen (29%) of the 45 sites (Fig. 2) have three or more beaked whale stranding events, accounting for 60 of the 331 events (18%). Five of the 13 have one or more live beaked whale stranding event. All 13 sites are bays of some kind, at least nine of which have strong headland-bay character. The sites (Fig. 2) are Geographe Bay[2] in Western Australia (11 events), The Coorong[3] in South Australia (6), Ocean Beach[2] in Tasmania (6), Cloudy Bay[2] in Tasmania (6), Coffin Bay[3]

[2]These sites also have one or more mass strandings of ten or more non-Ziphiid odontocetes.
[3]These have one or more non-Ziphiid odontocete strandings of less than 10 animals.

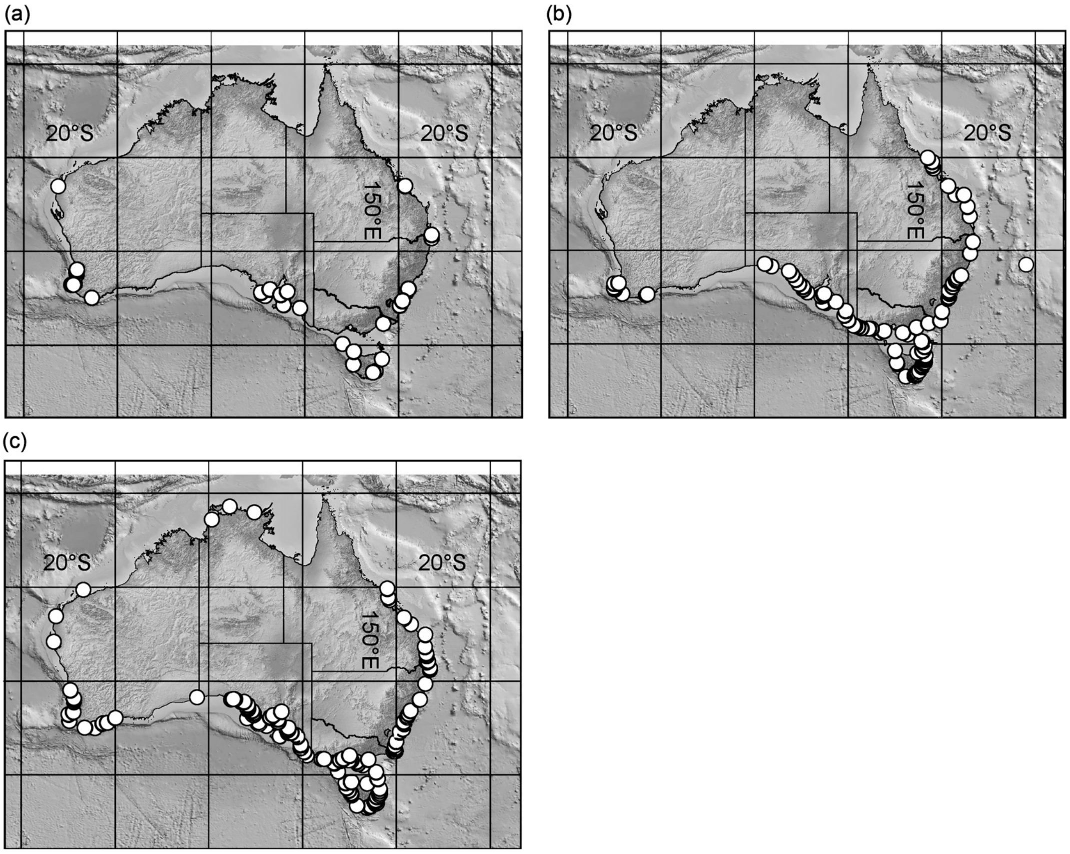

Fig. 4. Stranding locations of beaked whales (Ziphiidae) on the Australian coastline by status (live, passive, and unknown).
(a) Observed live strandings.
(b) Passive (carcass) strandings. Some would have been live strandings.
(c) Unknown stranding status. Skeletal material, or status not recorded.

in South Australia (5), Streaky Bay[3] in South Australia (4), Port Fairy[3] in Victoria (4), and three each for Bunbury (Western Australia), Elliston (South Australia), Sceale Bay (Victoria), Recherche Bay (Tasmania), Seymour[3] (Tasmania), and Yeppoon (Queensland). Bunbury could be counted as part of Geographe Bay, which is directly to its south, but it is a small headland-bay in its own right, and has been counted separately.

Hamilton and Lindsay (2014) noted 36 locations around Australia with one or more mass stranding of ten or more of the five non-Ziphiid odontocetes, with 66 such events in total. Nine of those sites also had one or more beaked whale stranding events. The nine sites are Cheynes Beach and Geographe Bay (both in Western Australia), and Cloudy Bay, Marion Bay, Ocean Beach, Perkins Bay, Pieman Heads, Sandy Cape and Tatlows Beach (all in Tasmania). Pieman Heads is an indented bay, Cloudy Bay is an indented bay with interior headland-bays, and the other seven sites have a strong headland-bay character.

Mysticete stranding locations

This section examines whether mysticetes strand in particular types of locations, and whether or not these are the same types of locations as the odontocetes. Twelve of 40 (30%) humpback whale stranding sites were headland-bays in planform or had headland-bay characteristics, 3 were deeply indented or complex coastlines (which can be viewed as topographic traps) and 9 were relatively featureless straight coastlines. These counts include live and passive strandings. The remaining 16 sites were named as points, capes, peninsulas, river mouths, lake entrances or inlets, and nearshore islands or reefs. In contrast, 36 of 42 (86%) minke whale strandings sites were headland-bays in planform or had some headland-bay character, 3 were topographical traps, and 3 were featureless. Of 16 live minke whale stranding sites, 12 had headland-bay character, and 3 were topographic traps.

Numbers in strandings

Beaked whales

Beaked whales stranded singly for 295 of 331 records (89% of recorded events). There were 35 events with 2 or more in a stranding (Table 1). Of these, seven have 3 or more individuals, with a maximum of 6 beaked whales in a single event. All 19 southern bottlenose beaked whale strandings were for a single individual. Four other species have also recorded single strandings only, but with 7 or fewer occurrences (Table 1).

Non-Ziphiids

The two balaenopterids had almost exclusively single strandings (minke whales 57 of 58 and all 48 humpback strandings). Eight of 48 humpback (17%), and 11 of 58 minke strandings (19%), were recorded as calves or subadults. These are lower bounds, since many records do not have details on age or length. In contrast, mass strandings of high numbers of individuals were recorded for the five non-Ziphiid odontocetes: 250 for false killer whales, two

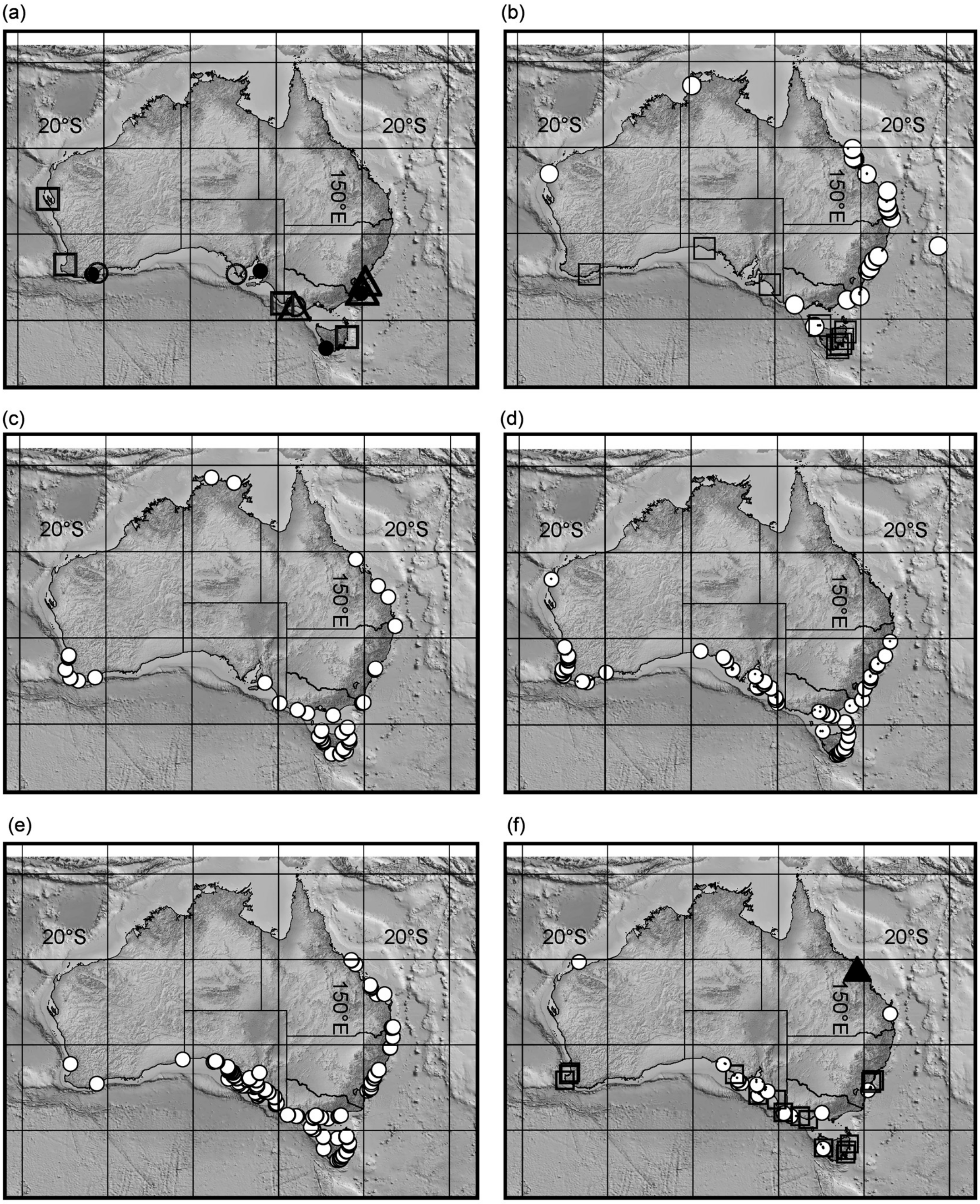

Fig. 5. Stranding locations of twelve beaked whale species around Australia (live, passive, and unknown status).
(a) Arnoux (●), Ginkgo-toothed (Δ), Shepherd's (□), True's (○).
(b) Blainville's (●), Hector's (□).
(c) Cuvier's.
(d) Gray's.
(e) Strap-toothed.
(f) Andrew's (□), Longman's (▲), Southern bottlenose (●).

events of 200 or more for long-finned pilot whales (one in South Australia, and one in Tasmania), 65 for sperm whales, 51 for melon-headed whales and 13 for killer whales. There were 66 strandings of 10+ individuals for the five non-Ziphiid odontocetes.

Temporal variation and seasonality

Total numbers of strandings in the database for all species examined (Ziphiid and non-Ziphiid) for the periods March to May, June to August, September to November, and December to February were 139, 130, 152 and 210. December to February (summer) was the only period with no recorded strandings north of 23°S, although few strandings for the selected species were recorded for those latitudes. Results of seasonal analyses obtained from a limited database must be made with some caution. If four three-monthly seasons are examined, and if it is considered that ten or more observations are required per season to have some chance of statistical reliability, then at least 40 observations are required for seasonal examinations. Not all species have this number of stranding records. The consideration of noteworthy examinations of seasonality below does not imply that they are statistically significant.

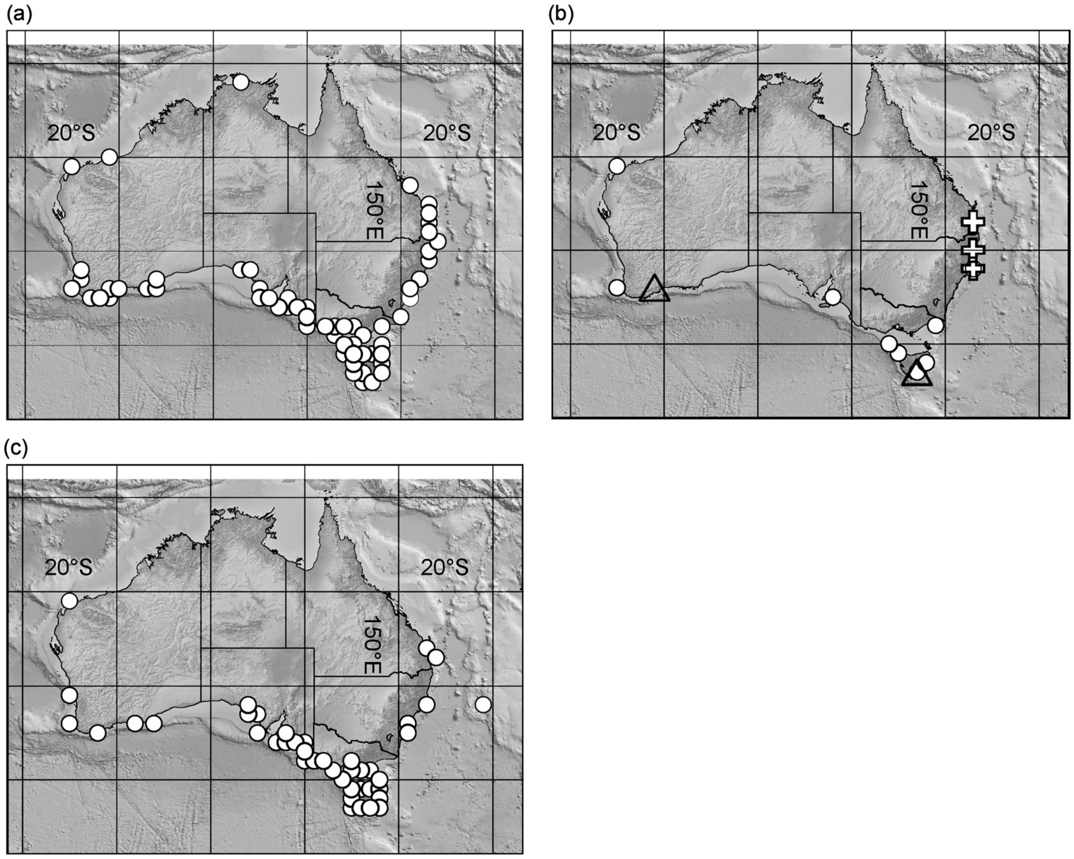

Fig. 6. Stranding locations of five non-Ziphiid odontocetes.
(a) Sperm whale. Single and mass strandings.
(b) Mass strandings of false killer whales (●), killer whales (Δ), melon-headed whales (✣).
(c) Long-finned pilot whale. Single and mass strandings.

Beaked whales

The highest number of beaked whale stranding records for the period 1869 to 2010 was 15 in 2005. Beaked whale strandings by month are shown in Fig. 8; there were 278 of known month and 53 of unknown month. The figure shows monthly aggregate totals for years 1869 to 2010, not monthly averages. For January to April the average aggregate total per month is 41, three times the average aggregate total of 13 events per month for July to December. Of 41 known live beaked whale strandings with known stranding month, 38 were for December to April, and none were for June to September. Of 10 live beaked whale strandings from Coffin Bay (135°15'E) to the southern Coorong (138°E) in South Australia, including the north side of Kangaroo Island, two were for November–December, and eight for January–February.

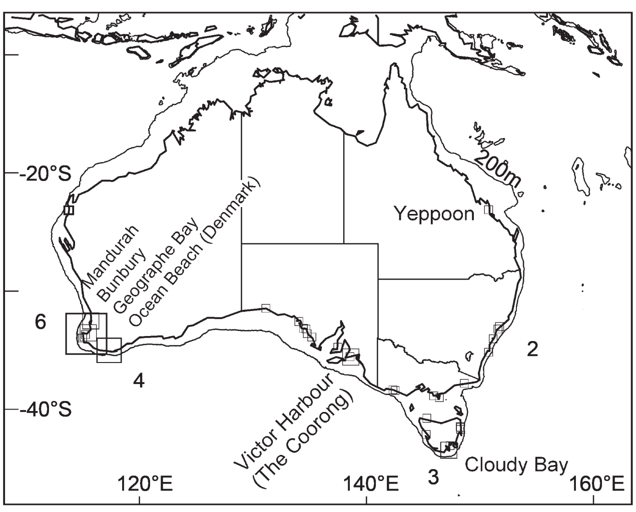

Fig. 7. Locations of stranding events of two or more beaked whales. Mother-calf pairs are not excluded. Numerals show the numbers in a stranding for the different sized open square symbols. The maximum in an event is 6 off Western Australia.

The data for two beaked whale species with more than 15 records showed clear seasonality in strandings. The strap-toothed beaked whale stranded 68 of 95 times (72%) over 1974–1984 in January to April. Gray's beaked whale stranded 29 of 60 times (48%) for 1990–2005 in December–January, and 48 of 60 times (80%) for December to April. No obvious seasonality was noted for strandings of Blainville's beaked whale (18 records), southern bottlenose beaked whale (15 records), or Cuvier's beaked whale (33 records for 1918–2009). For 1944–2007 Andrew's beaked whale stranded 10 times in January to June and once each in August, November and December. Of nine strandings with known month for Hector's beaked whale for 1990–2005, all but one in October were for February to April. All five Arnoux's beaked whale strandings are for December to February. All five Ginkgo-toothed beaked whale strandings for 1974–2009 were for May to August. Of the five Queensland stranding events north of 23°S (for 19.9 to 21.25°S) for June to August, three events were beaked whales (one Cuvier's and two strap-toothed). The others were a minke and a juvenile humpback.

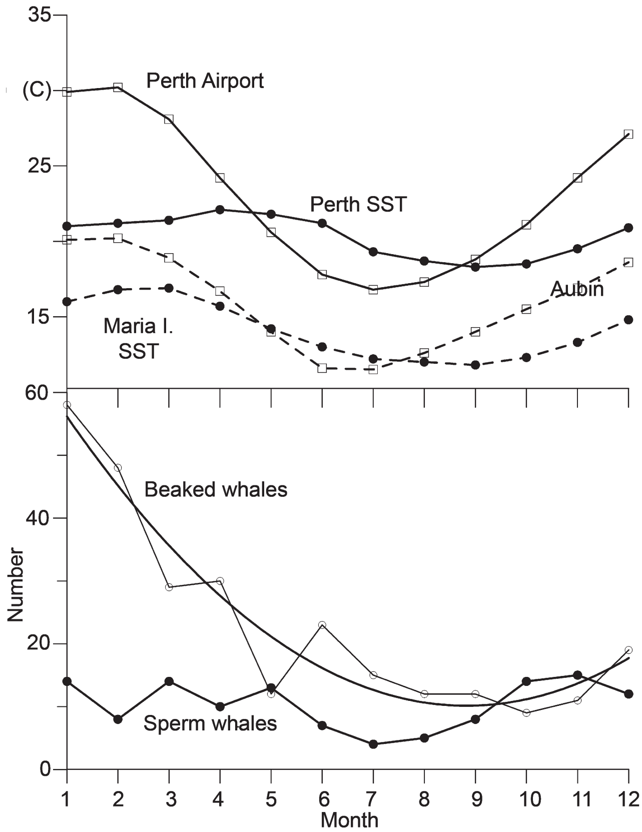

Fig. 8. Top panel: The yearly cycles of sea and air temperatures for the oceans off Perth (Western Australia), and Maria Island (Tasmania) (42.66°S, 148.02°E). The air temperatures are measured by land stations. Aubin is 31km from Maria Island. SST = sea surface temperature. Bottom panel: Total numbers of strandings by month for sperm whales, and for all beaked whale species combined.

For the 29 years from 1982–2010, 31 events were reported involving two or more beaked whales in a stranding (one per year), including mother-calf pairs. Without mother-calf pairs the rate may well be half this, but the information is insufficient to examine this point.

Non-Ziphiid odontocetes

For the 124 sperm whale records with known stranding month (Fig. 8), a lower number of total strandings occurred in June to September for the 101 years from 1909–2009 (an average aggregate total of 6 strandings per month compared to 12.5 in other months). Long-finned pilot whales (108 records) mostly stranded in October to March over years 1917–2009 (an average aggregate total of 13 events per month compared to 5 for other months). False killer whale strandings peaked in June and July for 1936–2009 (9 of 17 mass strandings were in these two months). The three melon-headed whale mass strandings for 1959–1988 were in July–August.

Mysticetes

For the period 1919–2006, humpback whales stranded more often in the months July to December (an average aggregate total of 6.5 per month, with a broad peak for October–November of 9.5 per month), than in January to June (an average aggregate total of 1.7 per month). For 1946–2005 minke whales stranded a total of 47 times over July to October, and 10 times in other months.

DISCUSSION

Geography, habitat and migration

The majority of strandings for beaked whales and the seven other selected cetacean species occur around the southern half of the Australian continent. Evans *et al.* (2005) have previously noted higher frequencies of strandings on the southernmost areas of Southern Hemisphere land masses. Only 6 of 717 strandings for the selected species are north of 17.8°S, all in the Northern Territory; three were beaked whales. The lack of northern stranding records does not appear to be due simply to a lower density of observers in tropical Australia, as a stranding record has been maintained. Chatto and Warneke (2000) list 57 cetacean strandings, including dolphins, in the Northern Territory from 1948 to 1999, including mass strandings of 54, 40 and 21 short-finned pilot whales (*Globicephala macrorhynchus*) from 1984 to 2004.

Relation of strandings to the distribution of live cetaceans

If the stranding data reflect distribution, all species examined appear to be infrequent visitors to Australia's tropical north. This is reasonably certain for the two mysticetes. The overall stranding patterns for the humpback whales are consistent with north/south migratory movements between Antarctic feeding grounds and subtropical breeding areas adjacent to the Australian coast, coupled with following of shorelines to the breeding grounds. Latitudes 15–18°S are the general northern limit of humpback whale migration routes to calving grounds for both Western Australia (Jenner *et al.*, 2001) and eastern Australia (Australian Government, 2004; Gales *et al.*, 2010). It appears that humpback whales do not stray in numbers much farther north than these latitudes. Humpback whales have been sighted in the Great Barrier Reef lagoon of Queensland as far north as 12°S (Kaufman *et al.*, 2010), but only two live sightings of humpbacks are recorded for the Northern Territory, with another in the Gulf of Carpentaria between the Northern Territory and Queensland[4]. No strandings have been noted for north Queensland towns such as Cairns, Port Douglas, Cooktown and Weipa (Fig. 1).

The general distributions for the five non-Ziphiid odontocetes (false killer, killer, longfinned pilot, melonheaded and sperm whales) are not well known, with most available information coming from strandings. Morrice *et al.* (2002) compiled killer whale sightings around Australia, from which they describe sightings in latitudes 0–25°S as rare. Killer whale sightings around Australia (Morrice *et al.*, 2002, their fig. 1) have the same general distribution as cetacean strandings in Fig. 3(a). Information on Ziphiid distributions is particularly dependent on strandings. As a point of interest, there are only four reported strandings of Shepherd's beaked whale, and these are widely separated from each other (Fig. 5(a)). In a remarkable coincidence, a pod of 12 Shepherd's whales was sighted near the stranding site in western Victoria in February 2012[5].

Shelf width

Extensive areas shallower than 200m occur over northern Australia (Fig. 1), and deep feeding cetaceans might be

[4]*http://data.aad.gov.au/aadc/whales/species_sightings*
[5]*http://www.antarctica.gov.au/science/cool-science/2012/whale-trackers-make-rare-sighting#prettyPhoto* [Accessed 13 November 2012]

rarely found in such areas. In contrast, the edge of the continental shelf is close to the coast for much of eastern and western Australia south of 25°S. To explain the more frequent Cuvier's beaked whale strandings in Tasmania compared to South Australia (see Fig. 5), Kemper and Ling (1991) proposed that the wide South Australian shelf and possible deep feeding behaviour in underwater canyons might keep beaked whales farther offshore than the narrow Tasmanian shelf. Tyack *et al.* (2006) have tracked Blainville's and Cuvier's beaked whales to over 1,200m and 1,900m deep respectively during feeding dives, supporting this idea. D'Amico *et al.* (2009; p.459) suggested worldwide beaked whale strandings occur where the 1,000m depth contour is close to shore (within 80km).

However, the wide continental shelf from 18–23°S on the east coast of Australia is not associated with an absence of strandings of the deep diving Blainville's and Cuvier's beaked whales (Figs 3, 4, 5). It is also noted that the South Australian shelf is up to 190km wide where Ziphiids have stranded (Fig. 3b). Kemper and Ling (1991) noted that more southern bottlenose beaked whales stranded in South Australia than Tasmania (see Fig. 5f). These observations imply that factors additional to shelf width may be important in determining where some beaked whale species strand. This is discussed further below.

Coastline characteristics

CLIFFS AND ROCKY COASTS

Hamilton and Lindsay (2014) noted a visual correlation between the absence of strandings and the presence of rocky sea cliffs which run unbroken for hundreds of kilometres on the coasts of Western Australia and South Australia (the Zuytdorp, Albany, Baxter, and Bunda cliffs) (Fig. 1). This was attributed to the reduced number or absence of beaches in these cliffed areas. If whales did strand at rocky cliffs it is unlikely they would be seen. They may well also keep a safe distance from the cliffs, being alerted by wave noise. Across much of northern Australia there may be a correlation between the lower numbers of strandings with rocky or reefy coasts, rather than with cliffs. In particular, the entire Kimberley coast of northwest Australia (15–18°S) is shown as rocky in Sharples *et al.* (2009), and there are no stranding records there, despite it being adjacent to humpback whale breeding grounds. Short (2006) describes laterite rocks and reef flats as common along the Northern Territory coast, with coral reef structures located immediately seaward of at least 1,430 beaches from the Kimberley area to Cape York. Most are barrier reefs backed by a lagoon and lower energy beaches. Only 16% of the bedrock-dominated Kimberley coast is sandy (Short, 2006). Elsewhere in Australia sandy beaches occupy between 38–66% of each state coastline (Short, 2006), indicating a potential for more strandings to be noted in those areas.

COASTLINE COMPLEXITY

Kemper and Ling (1991) noted a relatively low occurrence of cetacean mass strandings on the New South Wales coastline, possibly because of the relatively uncomplicated nature of the coast, whereas Tasmania showed many examples of strandings associated with complex topography (Nicol, 1986). The database has 71 strandings of two or more individuals (mother-calf pairs included) for Tasmania, and 6 for New South Wales for the five selected odontocetes. With islands included, this indicates that dual strandings upwards have occurred more than 4.6 times per length of coastline for Tasmania than for New South Wales. Coastline complexity clearly plays some part in cetacean strandings. However, headland-bays dominate the Australian mass stranding record for 10+ in a stranding (Hamilton and Lindsay, 2014), and these have relatively low complexity compared to re-entrant bays and bays with indentation ratio less than 2. This indicates that coastline complexity is not necessarily the major factor in mass strandings.

Many larger mass stranding events for the five selected non-Ziphiid odontocetes are associated with headland-bays or bays with headland-bay character (Hamilton and Lindsay, 2014). It is not possible from the available data to properly examine any relationship of beaked whale strandings with headland-bays, since there are too few mass strandings of beaked whales involving three or more individuals and dual strandings have insufficient information on sex to eliminate mother-calf pairs. What can be said is that (a) beaked whales have stranded in several headland-bays where larger mass strandings (10+ in a stranding) of other odontocetes have occurred and (b) with an increase in the number of beaked whales in a stranding event, or in the number of beaked whale stranding events at a site, the correlation with headland-bays also increases. At least 25 of 45 beaked whale strandings (56%) of two or more individuals (mother-calf pairs included) occurred in bays with headland-bay character, with three in indented bays. At least 9 of the 13 sites (69%) with 3 or more beaked whale stranding events have significant headland-bay character (Fig. 2). Five of 7 sites (71%) with three or more beaked whales in a stranding event were in a headland-bay, with one in an indented bay with interior headland-bays (Cloudy Bay), and one site poorly located.

Mass strandings

It is commonly reported that odontocetes often mass strand in high numbers, but that mysticetes do not (e.g. Sergeant, 1982), primarily related to social structure (see below). The Australian non-Ziphiid odontocete and mysticete strandings in our database follow this pattern. The two mysticetes had almost exclusively single strandings, and the five non-Ziphiid odontocetes had maxima of 13 to 250 in a stranding, with 66 strandings of 10+ individuals. However, the Ziphiid strandings do not follow this pattern. They fit between these two extremes.

D'Amico *et al.* (2009) list 136 worldwide beaked whale strandings of two or more individuals from 1874–2004, including Australian data. Forty-three of the 136 (32%) involved more than three animals, with ten of these for thirteen or more animals. D'Amico *et al.* (2009) observed 15 to be the usual worldwide maximum in a single event for any beaked whale species, with a maximum ever recorded of 28 Gray's beaked whales in a single event in 1874 at Chatham Island, New Zealand. Of the 35 Australian events with 2+ in a stranding, seven have more than 2 individuals, with a maximum of 6 in a single event (Table 1). Beaked whales stranded singly for 89% of recorded events (Table 1). Some beaked whale species have only single stranding events around Australia to date (Arnoux's, Ginkgo, Longman's, southern bottlenose, True's). Only Gray's, Shepherd's, and strap-toothed beaked whales have recorded strandings of more than two individuals.

Worldwide strandings of two or more beaked whales for 1950–2004 totalled 126, or 2.3 a year on average (D'Amico *et al.*, 2009). This is a lower bound, since some will not be discovered or recorded. For the 29 years from 1982–2010, Australia recorded 31 events involving 2+ beaked whales in a stranding (one per year), including mother-calf pairs. Without mother-calf pairs the rate may well be half this, but the information is insufficient to examine this point.

Species size, social group size and inshore-offshore species

There is no obvious correlation in the present data of whale species size with numbers in a stranding. The maximum numbers in strandings of any particular odontocete species in the Australian data matches two factors observed elsewhere in the world. One is the typical size of their pod or social group, and the degree of social cohesion within the group (Whitehead, 2003). The second factor is that offshore species live-strand more frequently than inshore species, with the implication that the offshore species may not have learned to navigate in coastal waters (Klinowska, 1985). For example, often killer whales live close to shore (e.g. Tyack *et al.*, 2006) and are not typically involved in mass strandings. In line with this observation, Morrice *et al.* (2002), and Ross (2006) state that killer whales rarely strand around Australia, with only three mass strandings noted (our database has two).

Humpback whales migrate northwards along the Australian east coast for several weeks in austral winter months in an almost continuous stream of individuals, with the peak northwards migration in June–July (Franklin *et al.*, 2011). They regularly occupy shallow areas such as Hervey Bay in Queensland, which is less than 18m deep, often with calves (Franklin *et al.*, 2011). They occasionally intrude into shallow enclosed areas with depths less than 30m such as Jervis Bay, New South Wales and sometimes Sydney Harbour (pers. obs.). However, the seasonal presence of large aggregates of humpback whales in shallow coastal waters has not led to mass strandings. This is probably because the amount of time spent close to shore on seasonal migrations habituates them to the presence of land from birth, and to navigating along coastal routes. When in coastal areas they can therefore be regarded as an inshore species, together with calves still 'learning the road' which are more susceptible to stranding mishaps, particularly during the return to Antarctica in October–November.

Seasonality in strandings

Summer beaked whale strandings

Beaked whale strandings overall occurred more for January to April than in other seasons (Fig. 8), and no live strandings were recorded for June to September. The exception is the Ginkgo beaked whale, for which all five strandings were in cooler months (May to August). The 101 year record for sperm whales (which are also deep diving odontocetes) does not show an enhancement in summer strandings (Fig. 8). Summer stranding of beaked whales would not be expected to relate to seasonal availability of prey, if beaked whales always feed at great depth. The circulations and properties of waters at 1,000m about Australia are generally decoupled from surface waters, and variations in temperature, salinity, and nutrients at 1,000m are small compared to differences in near surface waters. Prey at 1,000m would not be expected to be subject to the degree of seasonality in primary productivity of near surface waters.

Ross (2006) notes that the strap-toothed beaked whale may use waters adjacent to the continental slope for calving, but gives no evidence for this. Our database suggests another possibility. In South Australia in December–January one live straptooth beaked whale mother-calf pair stranded in Spencer Gulf, and one live pregnant Arnoux's beaked whale female stranded in St. Vincent Gulf. The gulf waters are less than 30m deep, far less than the 1,000 to 2,000m that some other beaked whale species are reported to dive to for food, and 200km distant from the edge of the continental shelf. It was earlier noted that of 29 dual beaked whale strandings, five were a female-calf pair, one included a calf, and ten others included a female. Four were not a female-calf pair, and nine had no identification on sex. The data suggest that beaked whales possibly frequent shallow or sheltered inshore waters for calving and subsequent resting of mother-calf pairs, rather than areas adjacent to the continental slope. This would potentially explain why beaked whales are not restricted to waters deeper than the continental shelf, despite their reported deep diving feeding behaviour.

Seasonality in mysticete strandings

The peak of the northwards migration of humpbacks along Australia's east coast is in June–July (Franklin *et al.*, 2011). Humpback strandings peak in July and October, indicating the northern migration and the southwards return to Antarctica. The spatial distribution of minke strandings is similar to that of the humpbacks (Fig. 3d), but strandings peak in June and September, indicating a migration cycle one month ahead of the humpbacks.

Seasonality in non-Ziphiid odontocete strandings

An interesting finding from the database is the much lower stranding rate of sperm whales around Australia in June to September over 101 years (half that of other months, see Fig. 8). This may indicate that a significant proportion of sperm whales which are usually present about Australia move away from Australia in June, returning after September. It is known that groups of larger male sperm whales move from Antarctic latitudes to equatorial regions at this time of the year for the winter breeding season, after which they return to Antarctic latitudes in summer (Culik, 2010). The coincident decrease in strandings suggests a similar movement of sperm whales away from Australia to deeper waters such as the warmer water breeding grounds, but whether of females and/or males cannot be determined from our data. Long-finned pilot whales strand in highest numbers from October to March in a quite different seasonal pattern than sperm whales. False killer whale mass strandings rise to a peak over May–June–July. This is possibly related to the peak migration time of mysticetes, which can form their prey.

Relation of strandings to sea temperatures

Evans *et al.* (2005) presented evidence of a 12–14 year periodicity in strandings for recently deceased or live cetaceans about Tasmania and Victoria. They postulated that this periodicity might relate to zonal trends in wind strengths, which cycle across quasi-decadal time scales. They found some correlation between the periodicity and years with stronger local winds in August (Southern Hemisphere winter). They loosely associated the periodicity with higher numbers of summer strandings, postulating these as being caused by enhanced winter productivity in coastal regions, caused by the stronger winds, bringing whales northwards.

Kemper and Ling (1991) tentatively associated a rise in summer stranding events for southern states with observer effort and Evans *et al.* (2005) invoked observer effort to explain lower numbers of winter strandings. However, the seasonality observed in the present paper, particularly for beaked whale strandings, corresponds more to seasonality in ocean temperatures, not to the summer air temperatures which may bring more observers to beaches and coasts (Fig. 8). Although the peak in January–February for beaked whale strandings shown in Fig. 8 is likely enhanced by observer effort, the expected corresponding enhancement is not seen in November–December, which are at background levels. While observer effort is a factor in reporting of strandings, it is apparently over-ridden for beaked whales by the correlation with sea temperatures.

There is a substantial lag of two to four months in ocean near-surface temperatures compared to air temperatures in southern Australian latitudes (Fig. 8). Two factors drive the lag. One is the thermal lag or thermal inertia of water compared to air, causing water to retain heat content far longer than air. The second is due to polewards flowing warm boundary currents on both sides of Australia, which bring warm subtropical waters to southern latitudes some months after they first arise from strong solar heating at latitudes 10–15°S.

The wind-driven subtropical circulation gyre of the South Pacific Ocean transports warm waters southward along the east Australian coast in the East Australian Current (EAC), a western boundary current. In the southern portions of the gyre, sea temperatures lag air temperatures because of the time taken to transport waters from one location to another. The EAC turns seawards near the latitude of Sydney, but some or all of this current or warm water rings spawned by it sometimes move southwards along the Australian coast to eastern Tasmania and much farther southwards (Harris *et al.*, 1987). Southern latitudes off south-eastern Australia consequently experience their warmest ocean temperatures in February–March, not mid-December to January (a two month lag), and their coolest ocean temperatures in or around September, not June–July (a three month lag). Maria Island (42.633° S, 148.083° E) off east Tasmania shows this pattern (Fig. 8, also see Harris *et al.*, 1987 and Ridgway, 2007).

A warm current also flows polewards off Western Australia, but is driven by sea surface height differences between the tropics and waters south of Australia, rather than being part of the wind driven Indian Ocean gyre. The Leeuwin Current brings highest near surface ocean temperatures to the Perth region of Western Australia in April–May (a four month lag), with coolest temperatures in September, not in June (a three month lag) (Hamilton, 1986; Rochford, 1984). This effect may continue eastwards. Continuations of the Leeuwin Current flow eastwards round The Capes into the Great Australian Bight to as far eastwards as Tasmania (Australian Government, 2007). Maps of the lag of sea surface temperature compared to air temperature for the Australian region are found in Li *et al.* (2013).

CONCLUSIONS AND SUMMARY

Information on strandings around Australia of beaked whales compared to other selected cetaceans are summarised as follows.

(1) Twelve species of beaked whales have stranded around Australia (Table 1). The maximum number of cetaceans observed in any one stranding event around Australia for 1868 to 2010 (143 years) is much less for beaked whales (maximum of 6), and two mysticete species (humpback (1) and Antarctic minke whales (2)), than for five species of non-Ziphiid odontocetes: false killer (250), long-finned pilot (200 to 250), sperm (65), melon-headed (51) and killer whales (13). The number of recorded beaked whale events with three or more in a stranding is seven, compared to 66 non-Ziphiid mass strandings with 10+ in a stranding for the five odontocetes just named. This makes it difficult to establish patterns of stranding behaviour for beaked whales. It is believed that the typical size of a species' pod or social group, and the degree of social cohesion within the group, is related to the maximum numbers in strandings (Whitehead, 2003). This would imply that beaked whales around Australia have smaller pods than the five selected non-Ziphiid odontocete species, but it may also be that as deep diving feeders they do not usually inhabit shallow waters in groups.

(2) For single strandings upwards, beaked whales have the same continental scale stranding patterns around Australia as the five non-Ziphiid odontocetes and the two mysticetes listed in the previous paragraph. Reported strandings predominantly occurred in the southern half of the Australian continent south of 20°S. For the humpback whale this appears related to their usual northern limits of migration along both the eastern and western coastlines of Australia to sheltered warm-water breeding grounds. For the non-Ziphiid odontocetes, this may occur because they strand more often than elsewhere in headland-bays (Hamilton and Lindsay, 2014). Wave and swell conditions south of 20°S are conducive to formation of headland-bays. Headland-bays are not numerous north of 20°S because Southern Ocean swell and swell from other latitudes is attenuated by greater travel distances, wide continental shelves and barrier reefs. Some beaked whale species strand on a particular part of the Australian coastline, for example Blainville's whales predominantly strand on the east coast. There are some indications that beaked whale strandings may occur more often in headland-bays, as for the five selected non-Ziphiid odontocetes, but this remains to be confirmed. There is an indication that Antarctic minke whales may also strand predominantly in headland-bays, whereas the humpback whale seemed

to strand almost anywhere. Although the causes for strandings of mysticetes and odontocetes may be different, the coincidence in their overall geographical stranding patterns allows subsequent more detailed examination and comparison of the characteristics of their stranding sites to be performed without complication.

(3) Of the six beaked whale species which exhibit apparent seasonality in strandings, five have most strandings in February–March (Andrew's, Arnoux's, Gray's, Hector's, strap-toothed), and a lower number of strandings in or about September, whereas all five Ginkgo strandings were in May to August. While observer effort will influence these numbers, they conspicuously lag the warmer air temperatures which affect observer movements to or from coastal zones by two to four months, and are directly correlated with the seasonal cycle of sea temperatures about southern Australia. The observed seasonality in beaked whale strandings is then indicated to be related to oceanographical factors, not solely to observer effort, as might be expected for aquatic organisms.

Grouping the stranding data for all beaked whale species overcomes some of the difficulties of having lower numbers of mass strandings to analyse than for other odontocetes about Australia, and brings out some seasonality very strongly. Comparing the composite behaviour with that of other cetaceans also allows more confidence to be placed in some observations. For example, the maximum number of beaked whales in stranding events about Australia is much lower than for five other odontocete species, and is higher than two mysticetes. Seasonal stranding patterns and stranding site characteristics of beaked whales around Australia are generally aligned more with those of other odontocetes than those of mysticetes. In general terms the examination indicates that sites of repeated beaked whale strandings, and sites of mass strandings of beaked whales, can be expected to be associated with the same coastal conditions on the average as mass strandings of other odontocetes around Australia, i.e. sites with a sandy headland-bay character, rather than the straight featureless coastlines often seen for the single stranding behaviour of humpback whales.

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