# Cetacean distribution in the coastal waters of the Sultanate of Oman

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ABSTRACT

Small boat surveys were conducted between 2000 and 2003 in three main regions of Oman's coastal waters: Muscat, the Gulf of Masirah and Dhofar. Survey data were analysed to calculate relative abundances of the seven most frequently encountered species in these areas. These include (in order of frequency) bottlenose dolphins (*Tursiops sp.*), long-beaked common dolphins (*Delphinus capensis*), humpback whales (*Megaptera novaeangliae*), spinner dolphins (*Stenella longirostris*), Indo-Pacific humpback dolphins (*Sousa chinensis*), Bryde's whales (*Balaenoptera sp.*) and Risso's dolphins (*Grampus griseus*). Other species observed include false killer whales (*Pseudorca crassidens*), blue whales (*Balaenoptera musculus*), rough-toothed dolphins (*Steno bredanensis*) and unidentified beaked whales. Encounter rates per distance searched were plotted by 0.1 x 0.1 degree grid cell, giving an indication of relative abundances and key areas of habitat used by each of the seven most frequently encountered species. These plots demonstrate that the nearshore areas of the Gulf of Masirah, as well as the coastal waters of Dhofar, are areas of concentration for the Arabian Sea's recently designated Endangered subpopulation of humpback whales, as well as Indo-Pacific humpback dolphins, which are considered Near Threatened on the IUCN Red List of Threatened Species.[1] The results presented here provide valuable baseline data for future research and help to inform conservation management efforts that are required to address the highly vulnerable status of the humpback whale and Indo-Pacific humpback dolphin populations in question.

KEY WORDS: ARABIAN SEA; GULF OF OMAN; DISTRIBUTION; HABITAT; BRYDE'S WHALE; BLUE WHALE; HUMPBACK WHALE; SPERM WHALE; BOTTLENOSE DOLPHIN; COMMON DOLPHIN; SPINNER DOLPHIN; RISSO'S DOLPHIN; INDO-PACIFIC HUMPBACK DOLPHIN; ROUGH-TOOTHED DOLPHIN

## INTRODUCTION

The Sultanate of Oman is a rapidly developing country on the Arabian Peninsula, with a landmass of approximately 300,000km$^2$ and over 3,240km of coastline (Al-Oufi, 2003 p.149). Politically and economically isolated and devoid of modern industry or infrastructure prior to 1970 (Kechichian, 1995), the country subsequently relied heavily on hydrocarbon resources which remain the primary economic driver. The economy is now diversifying, with emphasis on tourism, fisheries exports and port services (Ministry of National Economy, 2003). These sectors can lead to significant coastal and nearshore development pressures. It has been estimated that more than 80% of the country's population of over 2.3 million lives within 20km of the coast (Ministry of National Economy, 2003).

The oceanography of the Sultanate of Oman is complex. Coastal upwelling during the northeast and southwest monsoon seasons creates nutrient-rich 'temperate' marine conditions in an otherwise tropical marine climate (Banse, 1987; Burkhill, 1999; Kindle and Arnone, 2001; Sheppard *et al.*, 1992). During peak southwest monsoon months (July and August), sea-surface temperatures can drop to 16–17˚C (Sheppard *et al.*, 1992; Wilson, 2000). High nutrient levels in upwelled waters result in phytoplankton blooms and high productivity. Along the Arabian Sea coast of Oman productivity increases tenfold from less than 0.1g C m$^{-2}$ d$^{-1}$ during the southwest inter-monsoon period to above 1.1g C m$^{-2}$ d$^{-1}$ (Brock and McClain, 1992). This level of productivity is expected to support an abundance of cetacean prey (e.g. Papastavrou and Van Waerebeek, 1997) for a range of species with documented occurrence in Omani waters (e.g. Alling *et al.*, 1982; Baldwin, 1997; Ballance *et al.*, 1996; Gallagher, 1991; Papastavrou and Salm, 1991; Salm, 1991; Salm *et al.*, 1993). Baldwin *et al.*'s (1999) review of cetaceans in Arabian waters used this literature and other incidental/opportunistic sightings and strandings data to provide the most comprehensive published overview to date. However, with the exception of Ballance *et al.* (1996), which focused on offshore environments only, previous studies do not provide information on relative or absolute abundance, and limited data on habitat preference or ecology. As the rate and scale of development and associated human activities increase in Oman, it becomes more important to define habitats, and assess threats within those habitats, in order to design optimal management and conservation strategies (e.g. Bannister *et al.*, 1996; Evans and Hammond, 2004).

Geographic Information Systems (GIS) can be used to map cetacean distribution and abundance in relation to physical and environmental factors such as depth, slope, sea surface temperature and chlorophyll-a concentrations (e.g. Baumgartner *et al.*, 2001; Cañadas *et al.*, 2002; Davis *et al.*, 2002; Moses and Finn, 1997; Smith *et al.*, 1986; Waring

[1] IUCN. 2010. IUCN Red List of Threatened Species. Version 2010.4. [Available from: *http://www.iucnredlist.org*].

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*et al.*, 2001). These studies have, with varying degrees of statistical significance, determined correlations between environmental factors (particularly depth and slope) and cetacean distribution. Here we use GIS to analyse data collected during small boat surveys conducted in coastal waters of Oman. Observed distribution and relative abundance of a number of cetacean species are analysed to identify key areas for the most frequently encountered species and to provide a baseline against which to compare future research efforts in the face of increased coastal development and habitat degradation.

## METHODS AND MATERIALS

### Field surveys

Small boat surveys were conducted between January 2000 and October 2003 in three main locations; the Gulf of Masirah, Dhofar, and Muscat. Timing and locations of surveys are shown in Table 1 and survey tracks from these surveys are depicted in Figs 1a–c. Surveys were always conducted in the Gulf of Masirah in October and November, in the Dhofar region in February and March and monthly in the Muscat region throughout most of the three-year study period. One additional 3-day survey was conducted in Ras al Hadd in March–April 2001. Rough seas and fog generated by the SW Monsoon prevented small boat surveys along the Arabian Sea coast during the summer months (May–September). Survey effort was further constrained by the availability of funding and personnel, as all work was conducted on a volunteer basis. Furthermore, surveys in the Dhofar and Gulf of Masirah area were conducted with an aim to collect distributional, photo-ID, and biopsy data from the Arabian Sea's subpopulation of humpback whales, designated as Endangered by the IUCN in

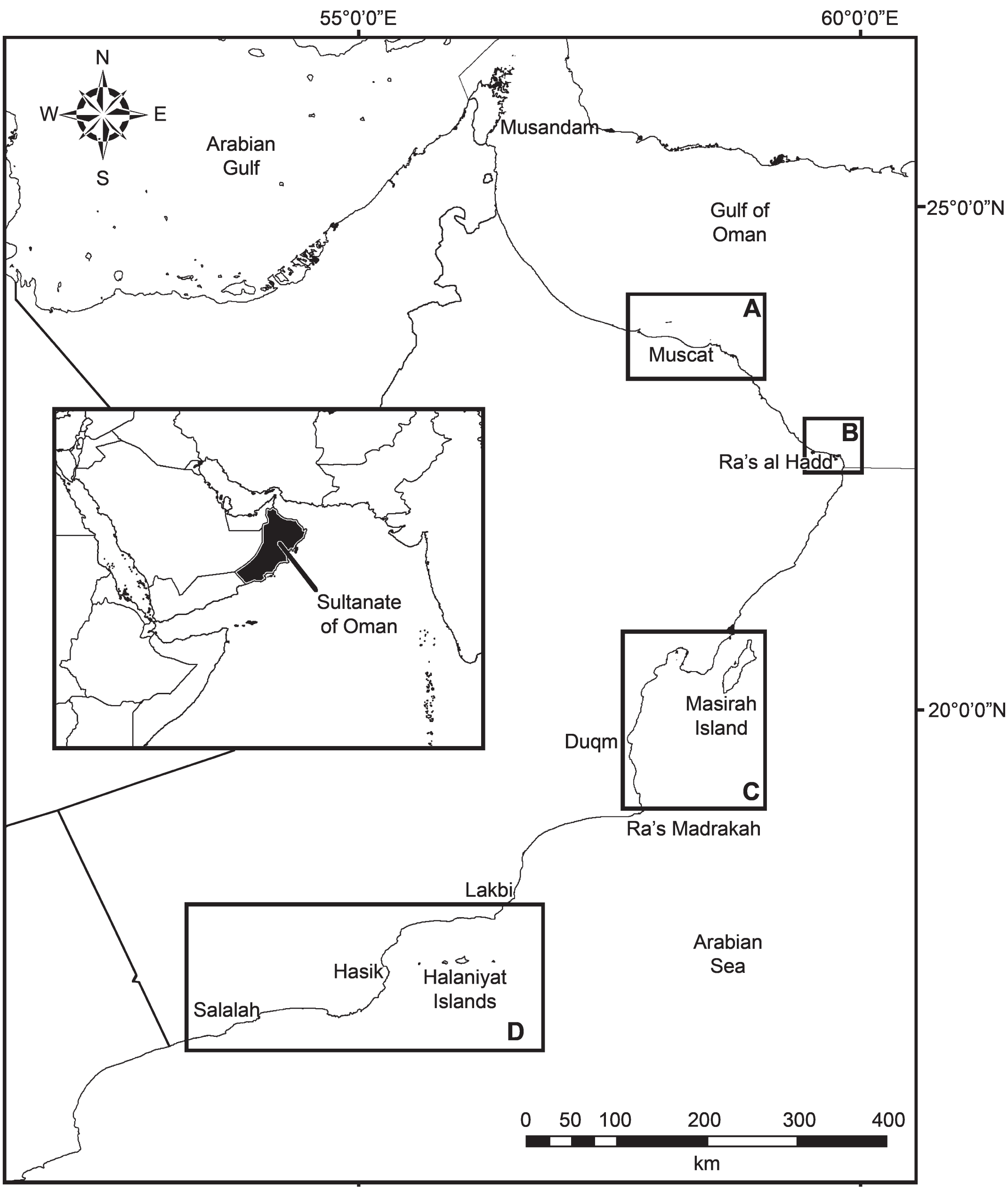


Fig. 1. Northern Indian Ocean and Arabian region highlighting Oman and the four main study regions (A–D) along the coast. A: Search effort in the Muscat region from 2001–2003 – on effort tracks = 2,264km. B: Ras al Hadd (not shown in detail as it is only 3 days of survey effort) – on effort tracks = 200.8km. C: The Gulf of Masirah (GoM) – on effort tracks = 2,555.24km. D: The Dhofar region – on effort tracks = 3819.71km.

2008 (Minton *et al.*, 2008). As such, areas of known or suspected humpback whale distribution (based on historical data and anecdotal reports) were targeted. However, within those general survey areas, tracks were designed to provide as much coverage of the area as possible and in as even a manner as possible, without taking into consideration the specific location of previous sightings.

The majority of surveys were conducted from a 6.5m rigid-hulled inflatable boat (RIB), powered by two outboard engines. Pre-determined survey tracks were plotted on bathymetric charts, and generally followed an irregular saw-tooth pattern along the coast. These were designed to cover different depth ranges within the logistical and safety limitations imposed by vessel size and nightly mooring opportunities. Exceptions to this general survey plan included surveys in January and February 2000, when two observers conducted opportunistic searches from vessels in transit around the Hallaniyat Islands (17.50°N, 56.00°E), maintaining records of effort and survey tracks, and during 15–17 October 2000, when a survey was conducted using a 5.5m fibreglass fishing skiff powered by a 25hp engine in the northern portion of the Gulf of Masirah (20.33°N, 58.25°E).

Surveys were conducted in 'closing mode', with search effort suspended when animals were sighted. Survey speeds ranged from 12 to 15 knots. Observers standing at deck level or seated on an A-Frame 3m above the sea surface scanned by eye areas forward of the beam. All observer activities were logged to the nearest minute allowing for post survey stratification of effort types. Weather conditions were recorded hourly and search effort was suspended in Beaufort sea-states of 4 or higher. Positional data were recorded using Garmin 12 or 12XL GPS units. Tracks were logged, with the

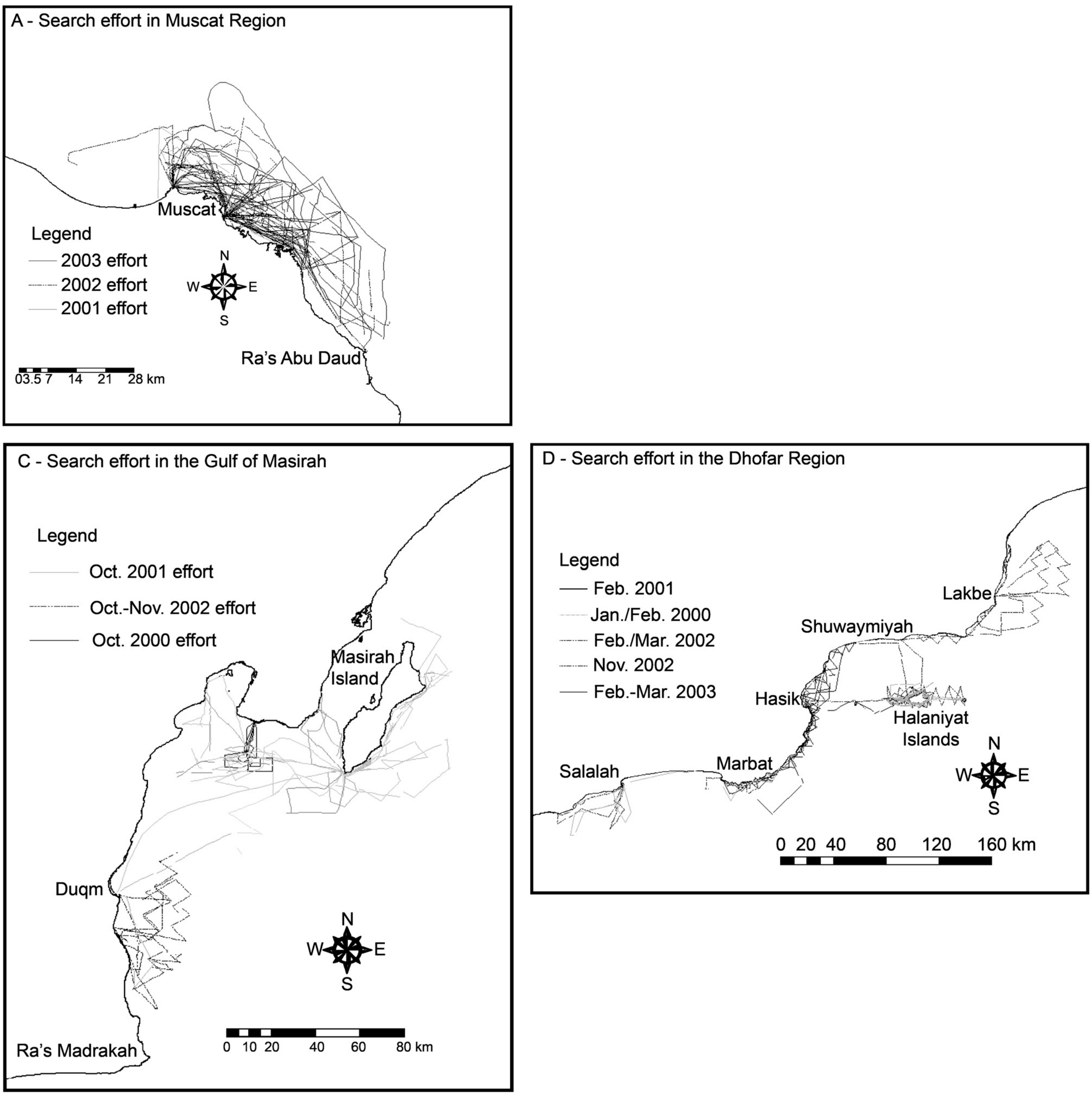


Fig. 1 (continued).

Table 1

Dates and locations of small boat surveys in Oman.

| Survey area | Survey dates | Effort hours* |
|---|---|---|
| **Muscat** | | |
| Monthly surveys | 15 Mar. 2001–15 Jul. 2003 | **104.21** |
| **Dhofar** | | |
| Hallaniyat Islands | 15–24 Jan. 2000/8–21 Feb. 2000 | 63.5 |
| Dhofar | 9–22 Feb. 2001 | 34.26 |
| Dhofar | 10 Feb.–2 Mar. 2002 | 62.37 |
| Hasik Bay | 24–26 Jun. 2002 | 4.32 |
| Sharbitat and Hallaniyats | 17–20 Nov. 2002 | 36.83 |
| Dhofar | 24 Feb.–19 Mar. 2003 | 116.31 |
| Dhofar (Hasik only) | 15–17 May 2003 | 2.17 |
| *Total* | | **319.76** |
| **Gulf of Masirah** | | |
| N Gulf of Masirah | 15–17 Oct. 2000 | 11 |
| Gulf of Masirah | 4–27 Oct. 2001 | 83.15 |
| Gulf of Masirah | 24 Oct.–16 Nov. 2002 | 58.2 |
| *Total* | | **152.35** |
| **Other areas** | | |
| Ras al Hadd | 30 Mar.–2 Apr. 2001 | **8.13** |
| **Shore-based observations** | | |
| Duqm | 10–13 Jun. 2001 | **25** |

*Effort indicates time spent actively searching for whales and excludes time spent working with whales, in transit, or on breaks.

vessel's position recorded every 30–45 seconds, and these and other positional data were imported into ArcView® (3.2a) for viewing and analyses at the end of each day. Depth was measured using a boat-mounted Raytheon L365 fishfinder (range to 650m), or by referencing British Admiralty ARCS charts (see below).

### Analysis

All sightings data made in the field were collated in an MS Access database (the Oman Cetacean Database, OMCD), along with other records of cetaceans from the region. For the purpose of this study, sightings and other data within the OMCD were classified into five effort categories:

Type 1 – sightings made while the vessel was on track during optimal search effort;

Type 2 – sightings recorded during surveys when at speed or with compromised observer effort;

Type 3 – sightings recorded while off effort during surveys or sightings made by the authors with no associated effort, as well as shore-based observations (February 2000, June 2001) and seismic survey data (e.g. Baldwin, 1997);

Type 4 – other incidental or dedicated sighting records from reliable third parties (incl. sightings associated with images, Ballance and Pitman, 1998; Mikhalev, 1997; Reeves *et al.*, 1991 and pers. obs. M.D. Gallagher 1970–1998; Salm *et al.*, 1993); and

Type 5 – incidental reports with detailed descriptions that support a species ID but cannot be confirmed by images.

Only Type 1 sightings were used in the calculation of encounter rates and relative densities in this study. Type 2–4 sightings were used in some behaviour and group composition analyses (see Minton *et al.*, in press) and also offer an additional source of data on species distribution outside survey areas and times. Type 5 sightings were taken into account when choosing survey areas, which were intended to target areas where humpback whales were known to occur, but were not included in any analyses.

Encounter rates were calculated for Type 1 sightings in three different ways: (1) Number of sightings per hour of search effort; (2) estimated number of individuals per 100km of survey trackline searched; and (3) number of cetaceans sighted per decimal degree searched in each 0.1 decimal degree (dd) × 0.1 dd cell. Grid cell size was determined as a compromise between accuracy in classifying habitat characteristics within grid cells, and the need for sufficient encounters within each cell to yield usable results (e.g. Hamazaki, 2002). On-effort portions of survey tracks were imported into ArcGIS and converted into shape files, one for each day's effort. These were plotted, and overlaid with a grid of 0.1 × 0.1 dd cells (approximately 11 × 11km). The geo-processing 'intersect' and 'dissolve' functions of ArcGIS were then used to calculate the total distance (in decimal degrees) surveyed on-effort in each cell.

Type 1 sightings data were imported into ArcGIS from the OMCD. The 'spatial join' function of ArcGIS was used to calculate the total number of groups and number of individuals in each cell for the most frequently encountered species (see Table 2 for species list). All Bryde's whale sightings are referred to as *Balaenoptera sp*. in this paper pending further analysis to determine species (e.g. Best, 2001; Sasaki *et al.*, 2006; Wada *et al.*, 2003).

Digitised depth files were generated for each of the four survey areas by creating points of known depth soundings from rasterised nautical charts (British Admiralty ARCS series, enabled with ARCS for GIS software – Intelliscan®). Kriging functions of ArcGIS Spatial Analyst were then used to interpolate these depth files and generate depth rasters with a mask applied to exclude terrestrial surfaces from grid cells overlapping the coast.

A further analysis was attempted by assigning each grid cell a depth and slope value, and plotting encounter rates against these to test for statistically significant relationships. However, initial approaches that would account for spatial auto-correlation did not yield statistically significant results, and are therefore not discussed in detail here but are the subject of ongoing analyses to be presented elsewhere.

Similarly, attempts were made to include statistical analysis of encounter rates in relation to remotely sensed chlorophyll-a and sea surface temperature data. The data obtained included 8-day averages of chlorophylla-a and SST during all the periods covered by our surveys. Initial inspection of the data revealed high seasonal and inter-annual variation in values for both of these parameters. For this reason the sample sizes of encounter rates per grid cell in relation to the time scale of the remotely sensed data (even if averaged for each survey) were too small to allow for meaningful statistical analysis.

## RESULTS

### Encounter rates and relative abundance

Surveys conducted between January 2000 and October 2003 comprised 585 hours and 8,840km of search effort. A total of 448 sightings of cetaceans were made, of which 304

Table 2

Number of on-effort (type 1 only) encounters/sightings and individual animals sighted per region, and encounter rates (for groups and individuals) per hour and per 100km searched.

| Survey area | | Muscat (monthly surveys 2000–03) | Dhofar (2000–03) | Gulf of Masirah (2000–03) | Ras al Hadd Apr. 2001 | Total/average |
|---|---|---|---|---|---|---|
| Effort hours* | | 104.21 | 319.86 | 152.35 | 8.13 | 584.55 |
| Total distance searched (km) | | 2,264.50 | *3,819.71* | 2,555.24 | 200.83 | 8,840.28 |
| Bottlenose dolphins | Sightings | 8 | 59 | 10 | 1 | 78 |
| *Tursiops sp.* | Individuals | 252 | 1,428 | 608 | 4 | 2,292 |
| | Sighting/hour | 0.08 | 0.18 | 0.07 | 0.12 | 0.11 |
| | Individuals/100km | 11.13 | 37.39 | 23.79 | 1.99 | 18.57 |
| Common dolphins | Sightings | 22 | 36 | 2 | 8 | 68 |
| *Delphinus capensis* | Individuals | 7,672 | 1,076 | 600 | 1465 | 10,813 |
| | Sighting/hour | 0.21 | 0.11 | 0.01 | 0.98 | 0.33 |
| | Individuals/100km | 338.79 | 28.17 | 23.48 | 729.47 | 279.98 |
| Spinner dolphins | Sightings | 32 | 2 | 2 | 4 | 40 |
| *Stenella longirostris* | Individuals | 8,130 | 420 | 200 | 1,375 | 10,125 |
| | Sighting/hour | 0.31 | 0.01 | 0.01 | 0.49 | 0.20 |
| | Individuals/100km | 359.02 | 11.00 | 7.83 | 684.65 | 265.62 |
| Humpback dolphins | Sightings | 0 | 29 | 5 | 0 | 34 |
| *Sousa chinensis* | Individuals | 0 | 234 | 116 | 0 | 350 |
| | Sighting/hour | 0.00 | 0.09 | 0.03 | 0.00 | 0.03 |
| | Individuals/100km | 0.00 | 6.13 | 4.54 | 0.00 | 2.67 |
| Risso's dolphins | Sightings | 3 | 3 | 0 | 0 | 6 |
| *Grampus griseus* | Individuals | 365 | 64 | 0 | 0 | 429 |
| | Sighting/hour | 0.03 | 0.01 | 0.00 | 0.00 | 0.01 |
| | Individuals/100km | 16.12 | 1.68 | 0.00 | 0.00 | 4.45 |
| Bryde's whales | Sightings | 5 | 1 | 4 | 0 | 10 |
| *Balaenoptera sp.* | Individuals | 7 | 2 | 6 | 0 | 15 |
| | Sighting/hour | 0.05 | 0.00 | 0.03 | 0.00 | 0.02 |
| | Individuals/100km | 0.31 | 0.05 | 0.23 | 0.00 | 0.15 |
| Humpback whales | Sightings | 0 | 33 | 23 | 0 | 56 |
| *Megaptera novaeangliae* | Individuals | 0 | 51 | 34 | 0 | 85 |
| | Sighting/hour | 0.00 | 0.10 | 0.15 | 0.00 | 0.06 |
| | Individuals/100km | 0.00 | 1.34 | 1.33 | 0.00 | 0.67 |

*Effort indicates time spent actively searching for whales and excludes time spent working with whales, in transit, or on breaks.

(68%) were Type 1 sightings. Encounter rates of sightings per hour of search effort, and estimated individuals per 100km searched are detailed in Table 2 and encounter rates of individuals in relation to distance searched per 0.1 dd × 0.1 dd cell are depicted in Figs 2a–g.

Fig. 3 shows the encounter rates (number of sightings per hour of search effort) for each survey region based on a compilation of all the survey effort in each region between January 2000 and October 2003. Additional species that were infrequently encountered on-effort were not considered. Similarly, encounter rates for the three-day Ras al Hadd survey held in March–April 2001 are not included in the figures.

**Additional species observed**

Sperm whales (*Physeter macrocephalus*) were encountered only once on-effort during surveys in the Dhofar region. Type 1–4 sightings recorded through 2003 included large groups of up to 25 animals, comprising mostly females and/or juveniles and only a few males. Of the 35 type 1–4 records of this species, 31 occurred in waters of 100m depth or greater. False killer whales (*Pseudorca crassidens*) were recorded only once on-effort during surveys, but were represented by 25 Type 1–4 sightings in the OMCD. Sightings were concentrated in the Muscat area and the Ra's Madrakah-Dhofar region. Reported group sizes ranged from 5 to 150, with calves confirmed on three occasions.

Only one blue whale (*Balaenoptera musculus*) was observed on effort, but the OMCD included a total of four confirmed records of this species up to October 2003, three from the Gulf of Oman (Muscat area), and one on-effort from Dhofar. The Muscat sightings occurred in the months of November and December, while the Dhofar sighting occurred in February. During all four sightings, the animals (three singletons and one trio) were observed to be milling in the same general area and diving for 3–10 minutes between surface intervals. Blue whales observed in Oman were all estimated to be under 20m in length.

Rough-toothed dolphins (*Steno bredanensis*) were observed only twice on effort during the period covered by these surveys. One of these sightings, a mixed group of Risso's and bottlenose dolphins was only identified as having included rough-toothed dolphins two years after the sighting when photographs were more closely examined.

**Species associations**

The most frequently observed association between cetacean species was that between common dolphins and spinner dolphins, which were observed in mixed groups in every survey area, but with highest frequency in Muscat ($n$ = 12), where they were also observed feeding together. Common dolphins were the only species with which spinner dolphins associated, but common dolphins were also observed with bottlenose dolphins ($n$ = 2). Bottlenose dolphins were seen in association with other species including Risso's dolphins ($n$ = 3), Risso's and rough-toothed dolphins ($n$ = 2), humpback whales ($n$ = 1), and Indo-Pacific humpback dolphins ($n$ = 2). One antagonistic inter-specific interaction

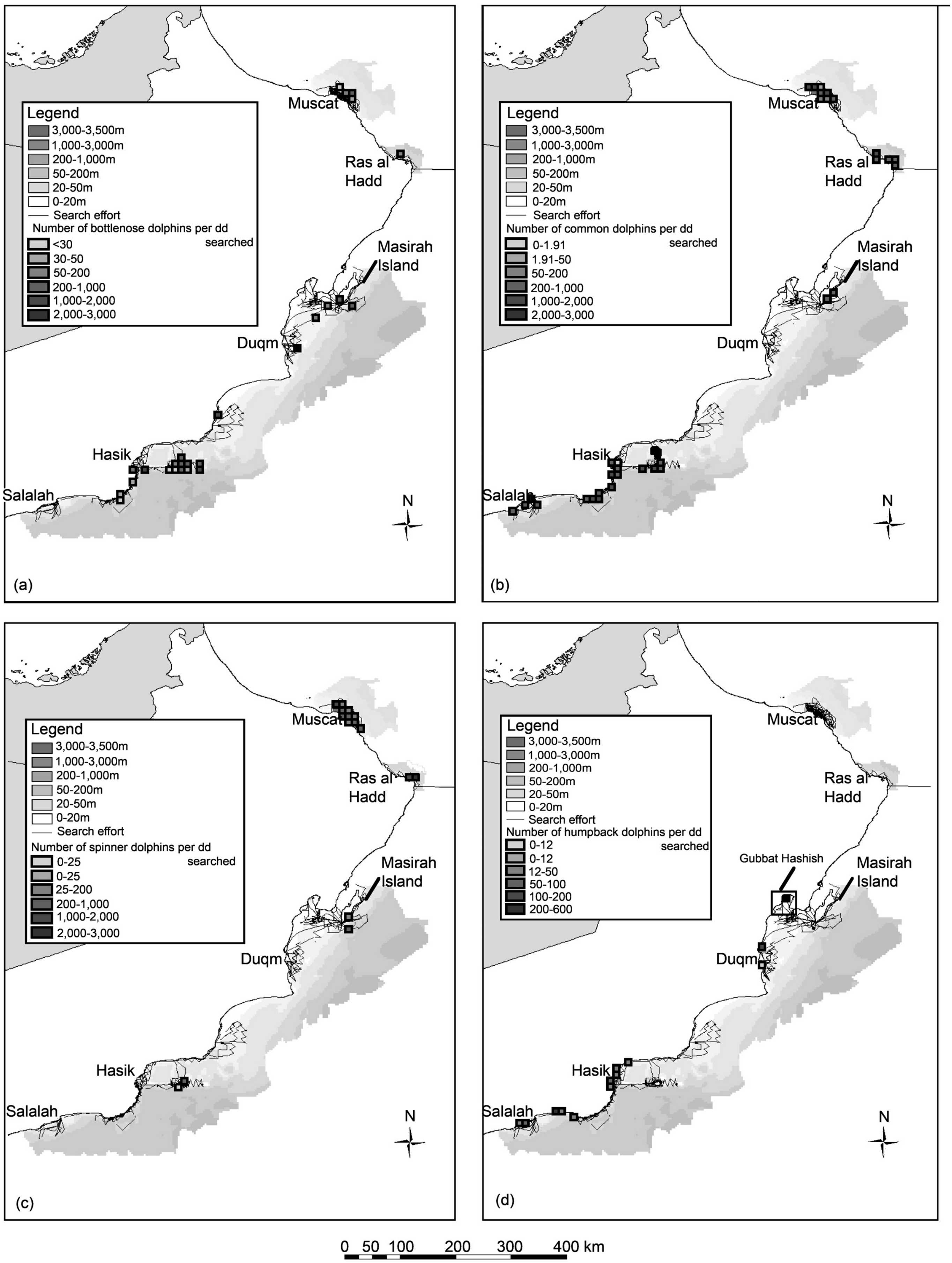


Fig. 2. Relative encounter rates per 0.1 × 0.1 decimal degree grid cell for the seven most frequently encountered species: (a) bottlenose dolphins, (b) common dolphins, (c) spinner dolphins, (d) humpback dolphins, (e) Risso's dolphins, (f) humpback whales, (g) Bryde's whales. Encounter rates were calculated as the total number of animals encountered in the grid cell divided by the distance searched (decimal degrees) in the grid cell.

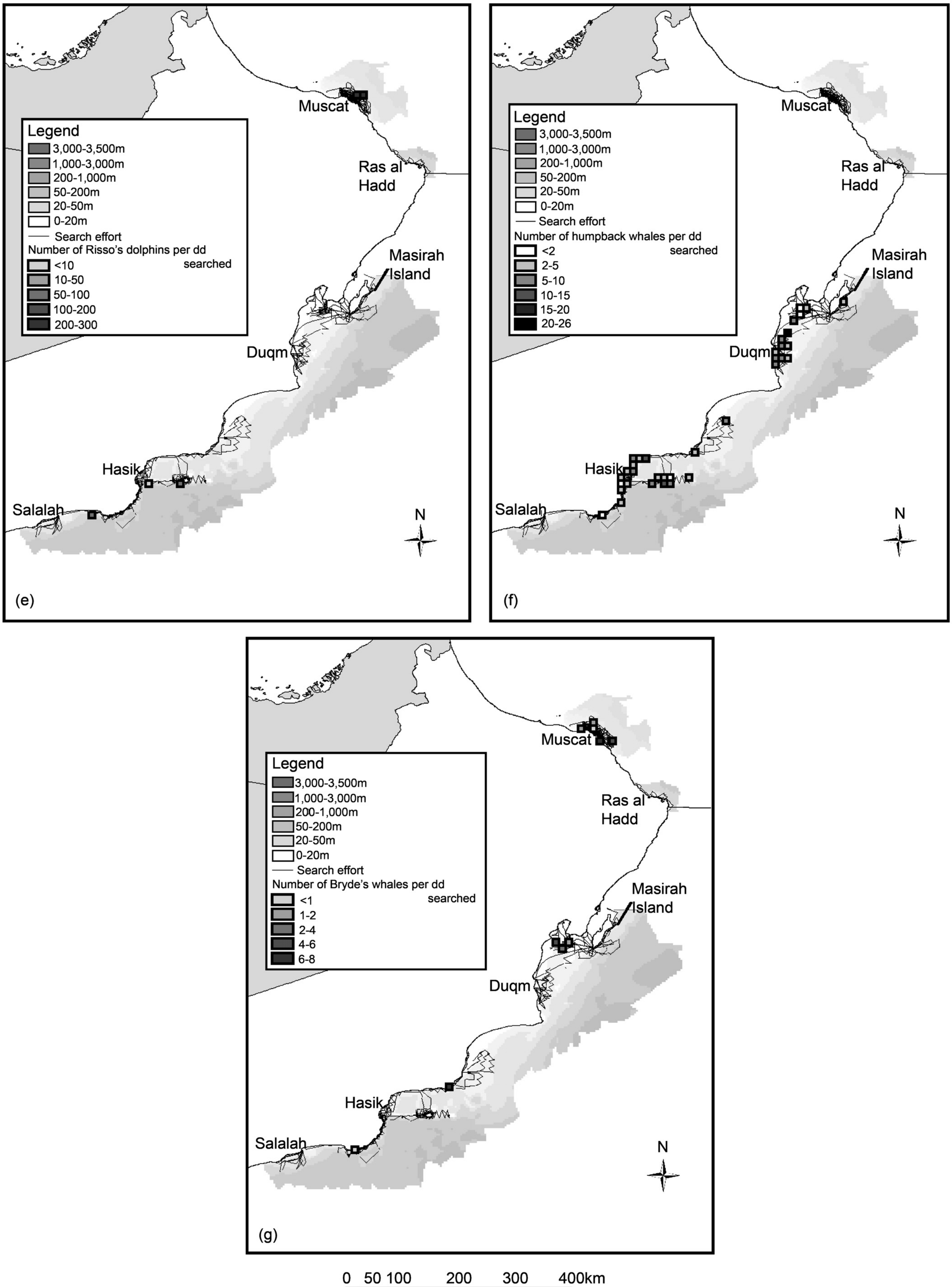


Fig. 2 (continued).

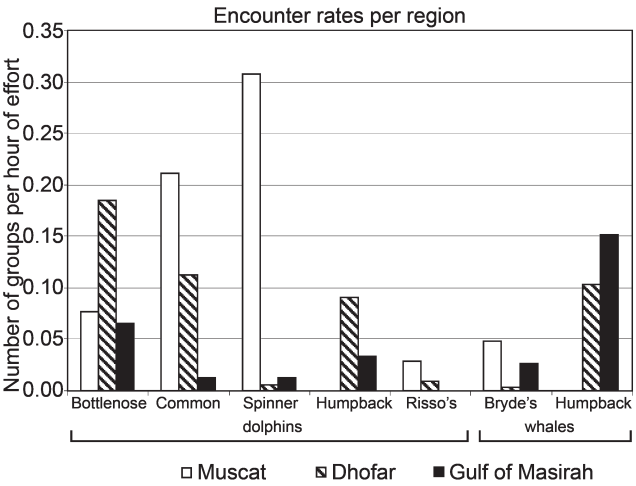


Fig. 3. Encounter rates (number of sightings per hour of search effort) in each region, for the most frequently sighted species.

was observed, when a group of 40 bottlenose dolphins were seen to harass a single Indo-Pacific humpback dolphin in Hasik, Dhofar, surrounding it, then body-slamming and biting it repeatedly over a period of thirty minutes.

## DISCUSSION

### Regional differences in relative abundance

The differences between survey areas in relative abundance of various species (highlighted in Table 2 and Figs 2a–g, as well as Fig. 3) are most likely linked to each species' demonstrated associations with specific depth and slope classes. Encounter rates for continental slope and deep water species such as spinner and Risso's dolphins (Baird, 2009; Perrin, 2009) were generally higher in the Muscat and Ras al Hadd regions, where a greater proportion of search effort was dedicated to grid cells in these categories. Conversely, nearshore and continental shelf species, such as Indo-Pacific bottlenose (Wang and Yang, 2009) and humpback dolphins (Parra and Ross, 2009) and humpback whales (Clapham, 2000) were encountered with greater frequency in the Gulf of Masirah and Dhofar, where a greater proportion of search effort was spent within the 200m isobath. However, there may be other factors influencing longshore distribution along the coast, such as upwelling-driven differences in water temperature and productivity, which were unfortunately beyond the scope of this study.

Sighting probability is also known to vary according to species' group size, body size, dive durations and surface behaviour (e.g. Mullin and Fulling, 2004), so it is likely that long-diving and/or cryptic species are under-represented in this study. Nonetheless, distributions for species reported here generally support those reported by Baldwin *et al.* (1999) and those determined for the same species in other regions. These are discussed in greater detail on a species-by-species basis below.

### Bottlenose dolphins

Bottlenose dolphins were the most frequently encountered species across surveys. Relatively high encounter rates across all three major survey regions (Table 2; Fig. 2a), indicate that *Tursiops sp*. are distributed throughout both the Gulf of Oman and Arabian Sea coasts of Oman. Observations of this species included at least two readily distinguishable forms, likely representing the two recognised species, *T. truncatus* and *T. aduncus* (Reeves *et al.*, 2002).

Bottlenose dolphins observed in the Muscat and Ras al Hadd survey areas were large (with some individuals estimated to exceed 3m in length), stocky, heavily scarred, and blunt-nosed. They were most often encountered in deeper offshore waters and were associated with other deep-water species, especially Risso's dolphins (3 out of 8 survey sightings). These groups most likely represent *T. truncatus* (Peddemors, 1999; Wang *et al.*, 2000).

Bottlenose dolphins observed in nearshore regions of Dhofar (representing all but one of the 59 Dhofar sightings) were generally smaller (averaging an estimated 2m in length, with no individuals exceeding 2.5m), exhibiting a long slender rostrum, pronounced dark cape and prominent speckling on the ventral surface of adults when exposed. They were most often found within 1km of shore in depths averaging 9.4m (SD 5.2) if the deepest sighting (120m) in Dhofar is excluded from the sample. In the shallow waters of the Gulf of Masirah, bottlenose dolphins were also smaller, more slender and had long rostra, although the dorsal capes were not as pronounced as those in Dhofar. The preference for nearshore and/or shallow waters demonstrated by bottlenose dolphins in Dhofar and the Gulf of Masirah is more in keeping with the reported habitat preference for *T. aduncus*, which is in water depths of less than 30m (e.g. Findlay *et al.*, 1992; Wang and Yang, 2009).

Although the Dhofar and Gulf of Masirah bottlenose appear morphologically to be *T. aduncus* (Perrin *et al.*, 2007; Wang *et al.*, 2000), planned genetic analysis of biopsies taken from nearshore groups of bottlenose dolphins in Dhofar, as well as a large number of samples that have been collected from beach-cast specimens all along the coast of Oman, may help to shed light on the taxonomy and possible population divisions of bottlenose dolphins in Oman. Even so, taxonomy of bottlenose dolphin populations worldwide is confused (e.g. Hoelzel *et al.*, 1998; Kingston and Rosel, 2004), and it may be some time before species and/or sub-species are clearly defined.

### Common dolphins

Common dolphins were the second most frequently encountered species across surveys, with an indicated continuous distribution along both the Gulf of Oman and Arabian Sea coasts of Oman. Recent morphometric analysis of skulls collected from the Arabian Region and elsewhere indicates that common dolphins in Oman are likely to represent the long-beaked form, *D. capensis tropicalis* (Jefferson and Van Waerebeek, 2002). However, these authors suggest a clinal distribution for *D. capensis capensis* and the sub-species *D.c. tropicalis*, the latter being most prominent (longest rostral length) off the Indian Subcontinent, with rostral lengths tapering toward the *D. c. capensis* form toward the east coast of Africa. It is therefore possible that some sightings off Oman represent *D. c. capensis* rather than the *tropicalis* form. Jefferson and Van Waerebeek (2002) also suggest that there may be some hybridisation between the two forms in regions of overlap. Group size ranged from 1 to 3,000, with 51 of the 68 on-effort sightings exceeding 100 individuals. Calves were observed in both the Dhofar and Muscat regions between December and February. Fig. 2b illustrates how encounter rates for this species peaked at the edge of the continental shelf in the 50–200m depth category. This is consistent with findings in other parts of the world (e.g. Cañadas and Hammond, 2008).

**Spinner dolphins**

Spinner dolphins were the fourth most frequently encountered species, with the highest encounter rates in the Muscat area (Fig. 2c). Morphologically, spinner dolphins observed off Oman may represent at least two forms or sub-species, with one form being slightly larger with a clear tripartite pattern, and the other being smaller with a less distinct pattern and more elusive habits. Morphometric analysis of skeletal material supports the hypothesis that Oman hosts a distinct form or subspecies, only slightly larger than the dwarf form described from Thailand (Van Waerebeek *et al.*, 1999), but the skeletal samples in the 1999 analysis could not be linked to external colouration on live animals, and neither field data nor genetic evidence are yet able to confirm the distribution or population identity of different forms in Oman.

Spinner dolphin distribution in the present study is consistent with that reported by Baldwin *et al*. (2000; 1999), but included sightings on the Arabian Sea coast of Oman (where Baldwin *et al.* reported no occurrence). As illustrated in Fig. 3, encounter rates for this species were much higher in the Muscat region (0.31 groups per hour) than in Dhofar or the Gulf of Masirah (both less than 0.01 groups per hour). Ballance and Pitman (1998) found spinner dolphins to be the most commonly encountered dolphin species in the deeper offshore areas areas of Oman covered by their study, and the higher encounter rates in the Muscat area may reflect the deeper, more steeply sloping nearshore coastline in that region. Estimated group size ranged from 20 to 700 individuals. Calves were observed in both the Dhofar and Muscat regions in the months of October and February.

**Indo-Pacific humpback dolphins**

Indo-Pacific humpback dolphins were encountered frequently along the Arabian Sea Coast of Oman, but not at all on the Gulf of Oman Coast (Fig. 2d). Type 3–4 sightings indicate a discontinuous distribution of this species, with one concentration found in the coastal waters around the Musandam Peninsula (Northernmost region of Oman and including the Straits of Hormuz – not included in our surveys), and another concentration south of Ras al Hadd on the Arabian Sea Coast. The strong preference for shallow inshore waters displayed by humpback dolphins in Oman is in keeping with distributions and habitat preferences reported in other parts of this species' range (e.g. Jefferson and Karczmarski, 2001; Karczmarski *et al.*, 2000; Parra, 2006).

Surveys conducted from 2000 through March 2002, contained little near-shore effort, while those conducted in Autumn 2002 and February–March 2003 included several days of dedicated near-shore effort. Encounter rates for humpback dolphins increased significantly during the latter surveys. Survey data and relative abundance calculations (Fig. 2d) indicate that certain areas are important for this species, including the shallow nearshore waters of the northern end of the Gulf of Masirah (particularly the 'Ghubbat Hashish' in the Northwest corner of the gulf), nearshore areas immediately to the North of Duqm, Hasik Bay in Dhofar, and the nearshore areas to the southwest of Salalah. The presence of small calves and the direct observation of feeding behaviour in all of these areas indicate that these are important feeding and breeding habitats.

The distribution, ecology, and taxonomy of this species is discussed in greater detail in Baldwin *et al.* (2004). Their reported sightings, together with those of this study, represent some of the largest group sizes ever reported for this species, with up to 100 individuals observed in a single aggregation. Additionally, Oman appears to hold the record body length for this species at 3.14m (a beach-cast male examined in December 2001).

**Rough-toothed dolphins**

Rough-toothed dolphins were not known to occur in Oman's coastal waters prior to 1998, when a previously misidentified partial skull was re-identified as *S. bredanensis* (Van Waerebeek *et al.*, 1999). Balance *et al*. (1996) recorded this species far offshore in their 1995 survey, but the two sightings made during this survey and a mass stranding of bottlenose and rough-toothed dolphins that occurred near Ras al Hadd in January 2002 (Collins *et al.*, 2002), are the first documented sightings of this species in Oman's coastal waters.

**Risso's dolphins**

Records of Risso's dolphins span both the Gulf of Oman and Arabian Sea coasts of Oman. This species was generally sighted in deeper waters further offshore (Fig. 2e), which agrees with distributions reported elsewhere in the world (e.g. Baumgartner *et al.*, 2001; Cañadas *et al.*, 2002; Hamazaki, 2002). Estimated group size of all Type 1–4 sightings ranged from 12 to 800, and on at least two occasions the species displayed a 'tail up' behaviour' where a large portion of the group would be stationary in the water, with tails exposed, for several minutes at a time.

**Sperm whales**

Soviet whaling fleets took a total of 954 sperm whales from the Arabian Sea between 1963 and 1967 (Mikhalev, 2000). While distribution maps show that few whales were taken off Oman in comparison to the Gulf of Aden and offshore waters at lower latitudes, some catches were attributed to the Arabian Sea coast of Oman. Mikhalev reported that foetus lengths from 121 pregnant females indicated that sperm whales in the region were adhering to a Northern Hemisphere breeding cycle, though his conclusions were based on a postulated 11–12 month gestation period for this species, contrary to the 15-month period accepted by most other researchers.

It is interesting to contrast the paucity of recent sightings of this species with the findings of Ballance and Pitman (1998) who found sperm whales to be the most frequently encountered cetacean species of their 1995 survey. This discrepancy is likely due to the concentration of nearshore effort in our surveys in Oman compared with the predominantly offshore nature of the 1995 Ballance and Pitman survey, a theory supported by the fact that all the

Type 1–4 records of this species in Oman are from water depths 100m or greater.

**Humpback whales**

Seasonal distribution, habitat use and ecology of this species are discussed in greater detail in Minton *et al.* (in press), and the discussion here will be limited only to the present study's implications for relative abundance and possible habitat preferences. With 56 on-effort sightings, humpback whales were the third most frequently encountered species on surveys. Surveys were designed to maximise encounters with humpback whales, targeting areas of suspected abundance on the Arabian Sea coast (the Gulf of Masirah and Dhofar).

The nearshore distributions demonstrated in Fig. 2f concur with the habitat preferences reported by Hamazaki (2002), who classified humpback whales as a 'North Atlantic Shelf Species' preferring depths of less than 400m. Moore *et al.* (2002) also found that humpback whales were more likely to occur on the 'middle' shelf, near the 50m contour. The concentration in nearshore/island areas in Oman is the most likely reason that this species was not observed at all by Ballance and Pitman (1998), whose survey concentrated on deeper offshore regions.

Although a few opportunistic sightings and anecdotal evidence indicate that humpback whales can be found in the Gulf of Oman, survey data reveal that the species is more abundant off the Arabian Sea Coast of Oman, and additionally suggest that the targeted survey areas, the Gulf of Masirah and the 'Kuria Muria Bay' of the Dhofar region (the area surrounding the Halaniyat Islands), are of particular importance for this population. Consistently high chlorophyll-a values in the Gulf of Masirah indicate high levels of productivity (Brock and McClain, 1992; Brock *et al.*, 1998; Marine Science and Fisheries Center Oman, 2001) and it seems likely that this region is an important feeding ground for humpback whales throughout the year. Variation in encounter rates between survey years and their possible relationship to seasonal and annual variations in sea surface temperature and chlorophyll-a concentrations are also discussed further in Minton *et al.* (in press).

**Bryde's whales**

Recent genetic analysis of sloughed skin samples and tissue samples collected from beach-cast whales, suggests the majority, if not all, Bryde's whales sighted in Oman to date are currently considered to be of the inshore form of Bryde's whale (*Balaenoptera edeni*) (T. Collins, unpublished data). Confirmed sightings have been recorded in every month except July, suggesting the species is resident off the coast of Oman (Baldwin *et al.*, 2000; Mikhalev, 2000). This species was heavily hunted in the Arabian Sea between 1963 and 1966 (Mikhalev, 2000). Full stomachs observed in these Soviet catches, coupled with direct observations of feeding activity and mother-calf pairs during our surveys indicate that the coastal waters of Oman may serve as both a breeding and feeding ground for this species as well as for humpback whales. Fig. 2g demonstrates how sightings of this species were limited to nearshore shallow waters, less than 50m depth, and how encounter rates were highest in the Gulf of Masirah and the southern portion of the Muscat survey areas. In Fig. 2g the southernmost sighting was a blue whale (*B. musculus*) while all others are likely to be the inshore form of Bryde's whale.

**Blue whales**

Blue whales were heavily hunted by the Soviet Union between 1963 and 1966, with a total of 1,294 whales taken from the Arabian Sea (Mikhalev, 1996; Mikhalev, 2000). These catches were identified as pygmy blue whales (*B. musculus brevicauda*) (Mikhalev, 1996; Mikhalev, 2000). Mikhalev (2000, p.149) provided a breakdown of catches per region within the Arabian Sea, but the 'Aden-Omani' region is combined ($n = 106$), and it is not clear how many of these animals came from the Omani coast. Mikhalev's (2000, p.144) distribution maps show three main areas of concentration within the Arabian Sea, including the Gulf of Aden, offshore from the southeastern tip of the Indian continent, and just below the equator offshore from Somalia.

Blue whale sightings recorded by Ballance and Pitman (1998) were concentrated around Sri Lanka and the Maldives. Anderson *et al.* (1999) reported strandings and sightings of blue whales in Maldivian waters, while Small and Small (1991), Alling *et al.* (1982), and Eyre (1995) all reported on sightings of blue whales during their surveys in the Northern Indian Ocean. It is unclear whether the paucity of sightings of this species off the coast of Oman is due to their prey preferences or reduced numbers from heavy Soviet whaling in the mid 1960's. The distribution of blue whales throughout the Southern Hemisphere and Indian Ocean is discussed in greater detail in Branch *et al.* (2007).

**Other species**

Additional species are known to occur in Oman, but were not encountered during surveys, and are therefore not described in detail here. These include the pantropical spotted dolphin (*Stenella attenuata*) (Baldwin *et al.*, 2000; Ballance and Pitman, 1998), the striped dolphin (*Stenella coeruleoalba*) (Baldwin *et al.*, 2000), the pygmy killer whale (*Feresa attenuata*) (Alling, 1986; Baldwin *et al.*, 2000), the melon-headed whale (*Peponocephala electra*) (Van Waerebeek *et al.*, 1999) and the killer whale (*Orcinus orca*) (Baldwin *et al.*, 2000). Reports of minke whale (*Balaenoptera acutorostrata*) and fin whale (*Balaenoptera physalus*) sightings off the coast of Oman in Baldwin *et al.* (1999) are not supported by photographic evidence, and the presence of these species in the region has since been suggested as highly unlikely (Baldwin, 2003). In addition, the Soviet catch data for the Arabian Sea referred to blue and Bryde's whales only (Mikhalev, 2000; Yukhov, 1969), and it seems unlikely that they would have overlooked minke or fin whales if they had been present in the region. It is possible that past sightings of minke and fin whales represented vagrants within the Arabian Sea, but it is more likely that they were misidentified.

**Problems of spatial and temporal scale**

Hamazaki (2002) discusses the limitations and potential biases of analysing cetacean distribution derived from cetacean surveys as a means of identifying critical or preferred habitats. One limitation is the sighting data themselves. Statistical analyses of relationships between cetacean sightings and habitat characteristics make the assumption that sightings are made in the cetaceans' preferred habitats. However, determining whether cetaceans are in their preferred habitat when sighted or in transit between one preferred habitat and another is not always possible.

Furthermore, while depth and slope are constant habitat characteristics that do not change from one survey period to the next, other environmental characteristics, such as chlorophyll-a concentrations and sea surface temperature (SST) can be highly variable between survey periods. Some studies have assumed that average seasonal values will not vary significantly over several decades (e.g. Gregr and Trites, 2001), or between survey years (e.g. Hamazaki, 2002), and have used averaged values of remotely sensed data from one particular period (deemed 'most seasonally typical') as a basis of comparison against several years' worth of sightings data. In light of the considerable inter-annual variability shown in oceanographic characteristics of the Arabian Sea (e.g. Brock and McClain, 1992), as well as in the SST and chlorophyll-a obtained for the periods of this study, this approach is not possible for Oman.

Furthermore, while instantaneous data may be available for the time of survey sightings, cetaceans may not respond to instantaneous changes of ocean conditions. There may be a significant time lag between an upwelling or algal bloom and a subsequent increase in cetacean prey availability. This time lag may affect each cetacean species differently, necessitating a detailed understanding of the life cycle and feeding preferences of a cetacean species' prey base (e.g. Baumgartner *et al.*, 2003a; Baumgartner *et al.*, 2003b) in order to make accurate assumptions. Such extensive knowledge of prey preferences and prey characteristics is not yet available for any cetacean species in Oman.

In Oman, baleen whales are documented to feed only on fish (Mikhalev, 2000), and very little is known about the preferred prey of other cetacean species. Stomach content analyses of beach-cast and by-caught cetaceans will help to yield more information on prey preferences, and consequently help direct future research on habitat preferences (Ponnampalam *et al.*, 2007).

## CONCLUSIONS

More extensive surveys of Oman's coastal and offshore waters are required to obtain more representative seasonal coverage and to include regions that were not accessible during the three years of survey effort discussed here. It is likely that future surveys will identify additional (seasonal) habitats of key importance to different cetacean species. Alternative survey methodologies, such as ship-based or aerial line-transect surveys, are also required in order to obtain absolute rather than relative abundance estimates for cetacean species in Oman. However, continued surveys geared toward collecting data on relative abundance will still yield valuable information on distribution and population trends, vital for future management and conservation efforts. In particular, analysis of relative abundance for the most frequently encountered species in this study indicates that the nearshore areas of the Gulf of Masirah (particularly the Ghubbat Hashish in the northern Gulf, and Duqm Bay), and Dhofar (particularly Hasik Bay) are of importance for Indo-Pacific humpback dolphins, while the waters just slightly further offshore from these same areas, with the addition of the Hallaniyat Islands, appear to comprise critical habitat for the Arabian Sea subpopulation of humpback whales, designated by the IUCN as Endangered in 2008 (Minton *et al.*, 2008). This population's ecology is discussed in greater detail in Minton *et al.* (in press). These areas should be considered a priority for future cetacean conservation and management measures.

Research to date has shown that at least four cetacean species occurring in Oman (spinner dolphins, Indo-Pacific humpback dolphins, humpback whales and blue whales), may be undescribed sub-species and/or isolated breeding stocks (Branch *et al.*, 2007; Pomilla *et al.*, 2006; Rosenbaum *et al.*, 2002; Rosenbaum *et al.*, 2009; Rosenbaum *et al.*, 2006; Van Waerebeek *et al.*, 1999). For these, and other as yet less studied species, continued research to refine population affiliations further and to obtain absolute abundance estimates and trend data is critical in a country which is undergoing rapid population expansion and development. Growth in hydrocarbon, shipping, fisheries, port/harbour and tourism sectors, all place direct pressure on cetaceans and their habitats. Since 2003, there have been notable increases in such pressure, including that in areas noted here as important habitat for some species. Oman's coastline already includes some of the busiest shipping lanes in the world (Ghose, 2010), a trend which is likely to increase significantly as a large industrial port is currently under construction in the area around Duqm on the Arabian Sea coast – the area coinciding with the highest encounter rates for humpback whales. High speed ferry services are being introduced in various parts of Oman, including in the Dhofar region where a service will run to and from the Hallaniyat Islands (Vaidya, 2008), where the only confirmed sightings of humpback whale mother-calf pairs were made and humpback whale song was recorded frequently. Furthermore, the number of registered fishing vessels has increased rapidly, more than doubling from just over 5,500 in 2006 to over 11,000 in 2008 (Ministry of National Economy, 2009). Without more extensive data and urgent management intervention, the possibly isolated and unique populations of cetaceans in Oman may not be sufficiently protected from these increasing threats.

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