A blue whale (*Balaenoptera musculus*) feeding ground in a southern Australian coastal upwelling zone

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ABSTRACT

A localised aggregation of blue whales, which may be pygmy blue whales (*B. m. brevicauda*), occurs in southern Australian coastal waters (between 139°45′E-143°E) during summer and autumn (December-May), where they feed on coastal krill (*Nyctiphanes australis*), a species which often forms surface swarms. While the abundance of blue whales using this area is unknown, up to 32 blue whales have been sighted in individual aerial surveys. Krill appear to aggregate in response to enhanced productivity resulting from the summer-autumn wind-forced Bonney Coast upwelling along the continental shelf. During the upwelling's quiescent (winter-spring) period, blue whales appear to be absent from the region. Krill surface swarms have been associated with 48% of 261 blue whale sightings since 1998, with direct evidence of feeding observed in 36% of all sightings. Mean blue whale group size was 1.55 (SD = 0.839), with all size classes represented including calves. This seasonally predictable upwelling system is evidently a regular feeding ground for blue whales, and careful management of human activities is required there.

KEYWORDS: BLUE WHALE; AUSTRALASIA; FEEDING GROUNDS; EUPHAUSIIDS; OCEANOGRAPHY; HABITAT

INTRODUCTION

Blue whales (*Balaenoptera musculus*) in the Southern Hemisphere were so severely hunted during the 20th century (Clapham *et al.*, 1999) that sightings are rare (Branch and Butterworth, 2001). Under Australia's Federal environment legislation they are listed as a Critically Endangered Threatened Species, and are the subject of a forthcoming Recovery Plan (Commonwealth of Australia, 1999). Feeding areas outside Antarctic waters are almost unknown. Most available information about blue whale feeding ecology comes from the Northern Hemisphere, where feeding grounds have been identified in coastal upwelling zones off the coast of southern California (Croll *et al.*, 1998; 2000; Fiedler *et al.*, 1998), Baja California (Reilly and Thayer, 1990; D. Gendron, pers. comm.), and in the Gulf of Saint Lawrence, Canada (Simard *et al.*, 1986; Sears *et al.*, 1990). Blue whales also feed in offshore upwelling areas in the eastern tropical and equatorial Pacific (Reilly and Thayer, 1990; Palacios, 1999). In all these areas, blue whales feed on abundant (in patches) euphausiid prey.

Historically, blue whales have rarely been sighted in Australian waters (Bannister *et al.*, 1996). During December 1995, a dedicated Blue Whale Cruise (under the auspices of the International Whaling Commission) was conducted through southern Australian waters, from Fremantle, Western Australia, to Hobart, Tasmania. During the cruise, an aggregation of blue whales was found off Discovery Bay near the Victoria-South Australia border (141°E). Many were identified by experienced observers as pygmy blue whales (*B.m. brevicauda*; see description in Ichihara, 1966). Some feeding behaviour and defaecation was observed, and euphausiids were collected from surface swarms for future identification (Kato *et al.*, 1996).

Historical data for western Victoria show some strandings and sightings records of blue whales since 1887 (Anon., 1999). Furthermore, the cold-water summer-autumn Bonney Coast upwelling has been known to exist in this area (e.g. Schahinger, 1987), suggesting that the presence of feeding blue whales might be related to this persistent and predictable oceanographic event. The Bonney Coast upwelling is a rare feature along the southern mainland coast of Australia, which is generally characterised as a nutrient-poor region fed by the warm water of the Leeuwin Current (e.g. Herzfeld, 1997). A yacht-based survey in February 1998 established that blue whales were again present in this region (author's data). Blue whales were found surface feeding in Discovery Bay and a longer-term ecological study was initiated, focusing on the linkages between blue whales and this upwelling habitat.

MATERIALS AND METHODS

Study area

The study initially focused on Discovery Bay, but was later expanded to cover the entire continental shelf from Robe, South Australia (139°45′E), to Port Campbell, Victoria (143°E), an area of approximately 12,000km^2 (Fig. 1). The east-west limits of the feeding area have not yet been conclusively delineated.

Survey methods

Aerial surveys

Surveys began in December 1998 and continued until May 2001. Most intensive coverage occurred during the summer-autumn upwelling seasons, with some additional coverage during winter and spring. Aerial surveys were designed to provide a measure of seasonal occurrence and general distribution, relative to environmental features such as the upwelling and bathymetry, and therefore were not intended as a method of establishing absolute or relative abundance of blue whales. Survey tracks covered much of the continental shelf and to at least 5 n.miles (9.25km) to seaward of it; flying further to seaward was precluded by cost and safety considerations. Complete coverage of the entire feeding area was not possible in any one flight, with flight frequency and tracklines determined by funding constraints, changing weather conditions, research needs and perceived changes in whale distribution with time. Spatial analysis of survey effort, whale distribution and biological oceanography will be addressed in subsequent publications.

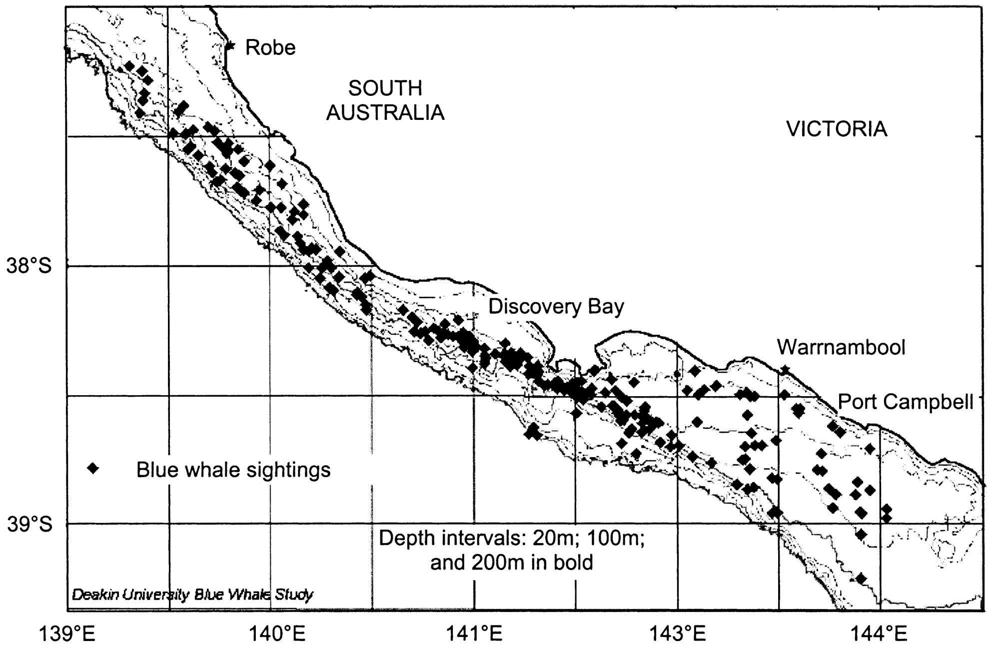

Fig. 1. Study area and blue whale sightings from the present study between December 1998 and May 2001.

Partenavia aircraft with at least two dedicated observers were flown at an altitude of 457m (1,500ft), at *ca* 140kts. Surveys were conducted in 'closing mode' i.e. whales were approached after being sighted from the trackline, to establish exact position, confirm species identity and to briefly observe behaviour. Environmental conditions, presence of other species (krill surface swarms, other marine mammals, seabird aggregations, fish schools), surface fronts, as well as fishing vessels, marine debris, oil spills and shipping were also recorded.

Boat-based studies
A yacht was used for short periods during February or March each season, for techniques including observation and videotaping of behaviour, net sampling of prey species, photo-identification, tissue biopsy/sloughed skin collection, faecal sampling, krill hydroacoustics, passive acoustic monitoring and basic oceanographic sampling.

Volunteer sighting network
Rock lobster fishermen routinely observe whales while searching for pot buoys. At the outset of the study, several were provided with a sheet showing distinguishing features of blue whales and some other whales which may occur locally (e.g. sei, humpback, southern right), and sightings record sheets. They were questioned about their sightings, including diagnostic features upon which identification was based. Sightings which could not be confirmed by the author as blue whales were discarded.

Incidental sightings
Experienced cetacean observers known to be transiting the area were asked to report blue whale observations. In addition, local charter boat operators reported some sightings. Sightings were also made from land, when blue whales were close enough to shore to be positively identified by body shape and markings.

Remote sensing
AVHRR SST (sea surface temperature) and SeaWiFs (ocean colour, or chlorophyll-*a* concentration) satellite data, and synoptic analysis weather charts, were accessed daily when available from August 1999 via the Internet (Fig. 2). These were used to monitor dynamics of prevailing winds, surface upwelling and associated primary productivity. For example, Fig. 2(a) shows that on 5 January 2000, strong SE to SSE winds were blowing along the coast. Although Figs 2(b) and 2(c) (originally colour images) lose detail and scale in the black and white rendition, they still clearly show the subsequent surface upwelling plume, as expressed in the depressed SST (7 January 2000) and enhanced chlorophyll-*a* concentrations (8 January 2000).

RESULTS

A total of 261 blue whale sightings involving 405 whales (mean pod size = 1.55, SD = 0.839; range 1-7) was recorded between 25 February 1998 and 28 April 2001.

Timing of occurrence of whales

Temporal occurrence of sightings from all aerial surveys is shown in Fig. 3(b). When compared to distance flown during aerial surveys (Fig. 3(a)), this indicates a seasonal presence/absence of blue whales, and also indicates trends in relative abundance during seasons, with more whales being sighted in March and April than in other months.

During the 1998/99 season, blue whales were first sighted on 8 December 1998 and last seen on 19 May 1999. It is possible that blue whales were present outside these times, but not recorded (this also applies to subsequent seasons). Fifty-two sightings totalling 77 blue whales (including one cow-calf pair) were made during the season. Blue whales were seen during five aerial surveys, with a maximum of 12 whales seen in any one flight. About one-third of all sightings were reported by lobster fishermen. No blue whales were sighted during aerial surveys in late May, in early August, early October or early November 1999, nor did fishermen report any sightings between May-December 1999.

During the 1999/2000 season, the first sighting was on 15 December 1999 and the last on 26 April 2000. There were 120 sightings for the season, for a total of 143 blue whales; of these, 97 sightings occurred during 13 aerial surveys. Aerial survey coverage was extended northwest and

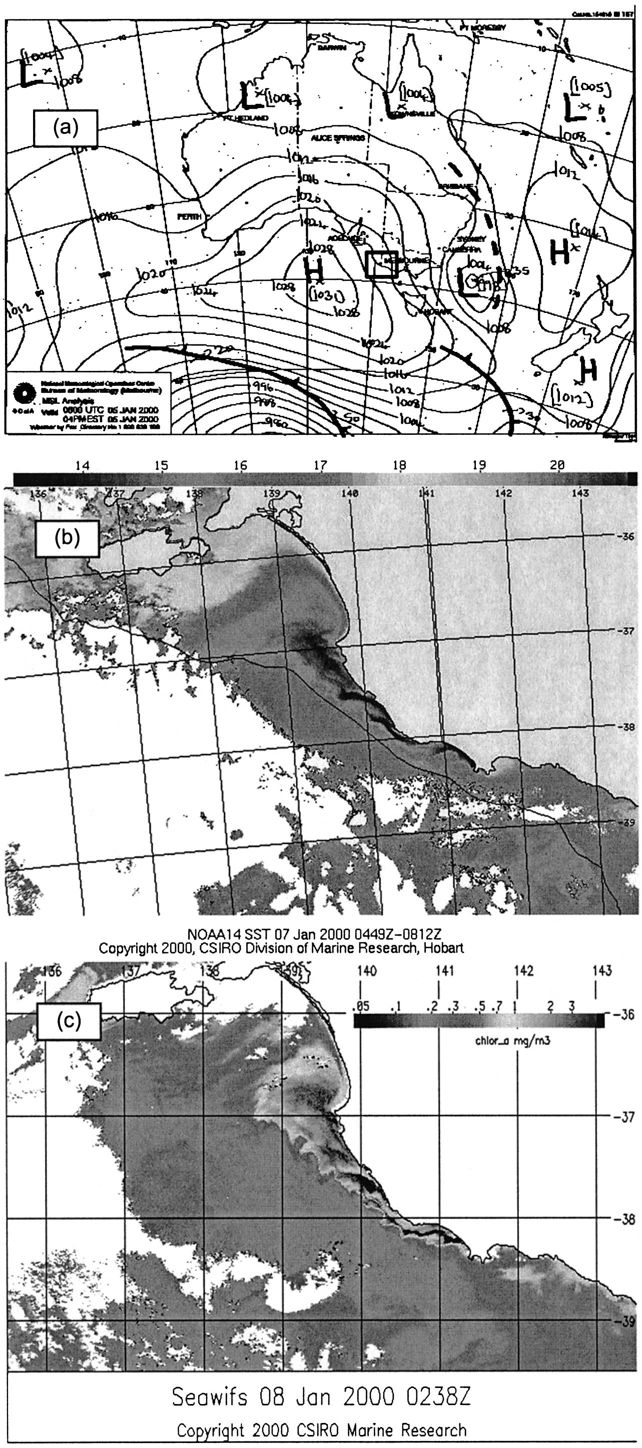

Fig. 2. (a) Typical 'upwelling' weather pattern producing strong southeast winds in the upwelling area (in box), 5 January 2000; (b) AVHRR image showing Bonney Coast upwelling, 7 January 2000; (c) SeaWiFs chlorophyll-*a* concentration, Bonney Coast upwelling, 8 January 2000. The surface upwelling plume runs northwest from the prominent cape at 141°30′E, Cape Nelson. Images courtesy of Bureau of Meteorology, CSIRO Marine Research, NASA and Orbimage.

southeast along the shelf from the previous season, roughly doubling the size of the survey area (see Fig. 3(a)). A maximum of 32 whales was seen in any one flight. Cow-calf pairs were sighted on three occasions. Only 5% of sightings were reported by fishermen, reflecting a reduced level of participation in the project by them. No blue whales were sighted during aerial surveys in August, October and November 2000, nor did fishermen report any sightings between May-December 2000.

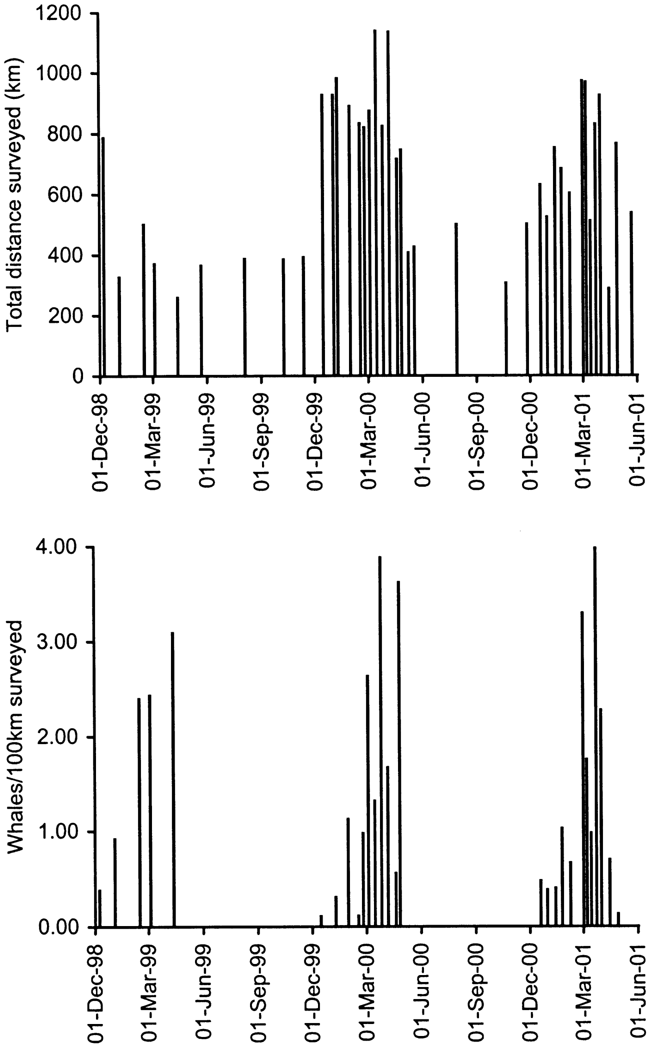

Fig. 3. (a) Timing of and total distances flown during aerial surveys; (b) Numbers of blue whales sighted per 100km flown during aerial surveys.

During the 2000/2001 season, the first sighting occurred on 19 December 2000 and the last on 28 April 2001. A total of 137 blue whales was sighted during the season, with 133 whales in 83 sightings during 13 aerial surveys. A cow-calf pair was sighted on one occasion.

The highest counts of whales occurred during some of the longest survey flights (see Figs 3(a), 3(b)). This may be explained by the fact that longer flights were possible during the period of most settled weather (March-April). This also happens to be the period when krill surface swarms are most abundant, possibly drawing greater numbers of blue whales to the area.

Distribution of sightings

Distribution of sightings is shown in Fig. 1. All sightings occurred on the continental shelf (< 200m water depth) between longitudes 139°18′E-143°03′E. Excluding this study, 45 (80%) of 56 previous blue whale sightings in Victorian waters lie within this area (Anon., 1999).

Evidence of feeding

Either feeding behaviour or defaecation were recorded in 94 (36% of total) sightings and whales were sighted within ~2km of krill surface swarms in 126 (48% of total) sightings. However on many occasions, krill swarms were sighted without blue whales in visible proximity. Obvious feeding behaviour included energetic surface lunges to engulf prey (whales often rolled onto one side, with the mouth wide open and the throat pleats distended) and similar subsurface feeding, visible from the aircraft. More leisurely 'skim' feeding (swimming slowly through dense prey surface swarms with the mouth agape) has also been observed on several occasions (see e.g. Watkins and Schevill, 1979, for discussion of mysticete feeding methods). Whales observed with distended throat pleats and baleen visible when sighted were assumed to have just fed. During a three-hour yacht-based observation on 24 February 2000, sub-surface feeding by five blue whales, within a radius of *ca* 2km, was inferred from frequent short-duration (1-2min) fluke-up dives, with whales resurfacing near the point of diving. Hydroacoustic backscatter levels measured from a yacht were high in areas where blue whales were presumed to be feeding at depth, compared to areas surveyed where blue whales were not present. Strong backscatter signals were observed at various depths between the surface and the seafloor (90m) in an area where one blue whale was feeding (T. Pauly and P. Gill, unpublished data).

Prey

Net sampling (70cm ring net, mesh size 500μm) of surface swarms on which blue whales were directly feeding identified the whales' prey as *N. australis*. This is a neritic species reaching *ca* 20mm, and is known from New Zealand and southeast Australia (Blackburn, 1980). Surface swarms have been observed during this study in all months from October to May, and appear to be largest (some swarms exceed 1,000m in length), densest and most abundant in March and April. This species migrates vertically through the water column (Blackburn, 1980; O'Brien, 1988) and is likely to be consumed by the blue whales at greater depths (e.g. Croll *et al.*, 1998).

Upwelling and marine productivity

During late 1999, the first upwelling plume appeared in SST imagery on 17 November, following strong southeasterly winds associated with the passage of a high-pressure system (see Fig. 2 for a similar event). Further upwelling pulses followed the passage of subsequent high-pressure systems, maintaining the upwelling surface plume of cold nutrient-enriched water, which was detectable until 24 April 2000.

During late 2000, SST images showing surface upwelling first appeared on 13 November and the upwelling plume was detectable until 9 April 2001. Surface temperatures within the upwelling plume, as shown by AVHRR imagery, may be as much as 5°C cooler than surrounding waters. Chlorophyll-*a* concentrations (as shown by SeaWiFs imagery) may be elevated up to >4 mg/m^3, an order of magnitude or more above those of surrounding waters (see Fig. 2). Phytoplankton-rich upwelled waters are often visible during aerial surveys, with visible oceanic fronts clearly corresponding with those shown in satellite imagery. As shown by SeaWiFs imagery (P. Gill, unpublished data), enriched waters appear to be present for some time after active upwelling ceases, both between active upwelling pulses and after the period of upwelling-favourable wind forcing ceases.

DISCUSSION

Links between coastal upwellings, euphausiids and blue whales are apparent at a range of sites, notably in North America (Simard *et al.*, 1986; Reilly and Thayer, 1990; Sears *et al.*, 1990; Schoenherr, 1991; Croll *et al.*, 1998; 2000; Fiedler *et al.*, 1998). It appears that similar links exist in the Bonney Coast upwelling region of southern Australia. Large-area AVHRR SST images show that this seasonal upwelling zone is the most prominent in southern Australian waters (CSIRO, 2001). It occurs when high pressure cells are far enough south for their southeast wind component to be roughly parallel to this northwest-trending coast, i.e. between the months of November/December - March/April (Lewis, 1981; Schahinger, 1987). This period coincides with the presence of blue whales in the region. During late autumn, winter and spring the highs move north, prevailing winds are onshore, the upwelling is quiescent, and blue whales appear to be absent from the region.

N. australis is reported to have a production-to-biomass ratio higher than any other euphausiid (Ritz and Hosie, 1982). It is associated with an upwelling plume in New Zealand (Bradford and Chapman, 1988), and is consumed by humpback whales in New Zealand and Tasmanian waters (Dawbin, 1956; Gill *et al.*, 1998), while its congener *N. simplex* is prey of blue whales off Baja California (D. Gendron, pers. comm.). The surface distribution of *N. australis* in the present study, as determined from aerial surveys, essentially mirrors the distribution of blue whales. *N. australis* is abundant along the Bonney Coast upwelling surface plume, and the waters immediately to its east, where sub-surface upwelling is thought to occur (P. Gill, unpublished data). However, more extensive aerial surveys are needed to establish its possible distribution (and that of blue whales) outside this area. It commonly forms daytime surface swarms, at various times of year (O'Brien, 1988), as described for its congeners elsewhere (e.g. *N. simplex*, Baja California; Gendron, 1992). The surface swarming behaviour of *N. australis* has greatly facilitated this study so far by enabling the detection of swarms without the need for logistically complex hydroacoustic or net sampling surveys. However, future studies should use these methods to investigate sub-surface distribution of krill swarms. The ecology of *N. australis* in this area has yet to be properly investigated, but assuming predictability of the upwelling and its enhanced productivity during summer and autumn, it is likely that the presence and abundance of *N. australis* swarms is also seasonally predictable.

Given the direct evidence that blue whales feed regularly on *N. australis* swarms, and the large number of blue whale sightings that have been recorded since this study began, it is likely that as long as the weather patterns and oceanography which drive the seasonal upwelling in this region remain relatively stable (and human activities do not displace them), blue whales will continue to feed in this area. Fin whales (*B. physalus*; $n = 3$ sightings) and sei whales (*B. borealis*; $n = 6$ sightings), both rarely seen in Australian coastal waters, have also been observed in the feeding area. The timing of the blue whales' presence in this temperate area, which coincides with the Antarctic baleen whale feeding season, tends to support the hypothesis that these are pygmy blue whales, which are thought to mostly inhabit waters north of the Polar Front (Kato *et al.*, 1995). However, their sub-specific identity and provenance are not yet proven: so far there are no photo-identification resights with other areas, and visual, photogrammetric, genetic and acoustic techniques to discriminate between blue whale sub-species are still inconclusive (see Donovan *et al.*, 1996; IWC, 2002, pp.205-6; Ljungblad *et al.*, 1997; 1998; McCauley *et al.*, 2001).

Management issues are posed by the presence of significant oil and gas reserves in the feeding area, by a major shipping lane intersecting it, and potentially by fisheries, and by whalewatching tourism (which is as yet undeveloped). Given the conservation status of this species, the scarcity of known feeding areas in either hemisphere and its relative accessibility (off Australia's populous south-east coast), this feeding area offers a rare opportunity to increase knowledge of blue whale biology and ecology and that of their prey. It also provides management agencies with an opportunity to devise and implement management initiatives which will contribute towards the continued survival of blue whales in this region.

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