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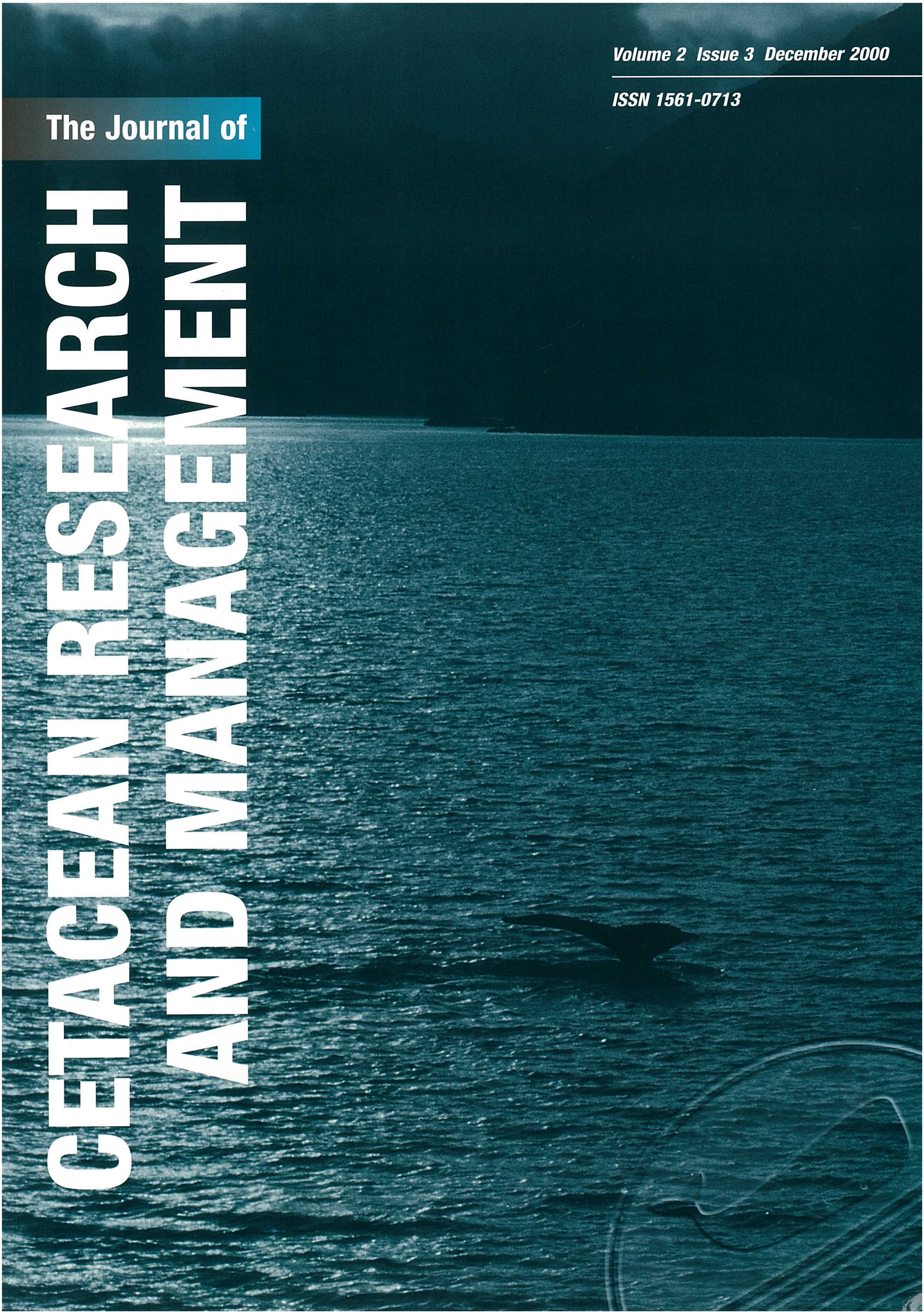

Contents

Editorial

Welcome to the final issue of the second volume of the *Journal of Cetacean Research and Management*. Year 2000 has proven to be another good year for the Journal. A total of 29 papers have been published involving some 115 authors from 17 countries (including Europe, Africa, Asia, Australasia, North America and South America). I am particularly pleased at the wide geographic spread and range of disciplines include and believe that the published papers are leading to the better conservation and management of cetaceans throughout the world. An index to Volume 2 appears at the back of this issue.

The present issue again covers a broad range of subjects, areas and species. In addition to providing information from less well-studied areas (including the Cook Islands, Ecuador, Grenada and the South China Sea) and species (the North Pacific right whale, the spectacled porpoise and the northern bottlenose whale), it also shows the value of some of the newer research methods in conservation studies (such as time-depth recorders, passive acoustics and the use of wavelet transformation in photo-identification studies).

Finally, I would like to thank Erika Csicsila who stepped into the role as Publications Secretary whilst Helen Sharp was on maternity leave and did a marvellous job with a wonderful smile!

G.P Donovan
Editor

Humpback whales in the Southern Cook Islands, South Pacific

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ABSTRACT

The presence of humpback whales in the Southern Cook Islands (South Pacific) was investigated during a three-week exploratory survey conducted at Palmerston Atoll in September and October of 1998 and during a three-month survey conducted at Rarotonga, Aitutaki and Palmerston Atoll from July to October in 1999. During a total of 48 survey days in both years and all areas, 50 sightings of 83 humpback whales were made. All classes except mother/calf/escort trios were observed, including singers, mothers and calves, and one competitive group. To date, 31 humpbacks have been individually identified from natural markings, 29 sloughed skin samples were collected for genetic analysis and 15.6 hours of song recordings were made. Reports of whales in other areas of the Cook Islands were also noted, and included records of mother/calf pairs. The Cook Islands region appears to represent a breeding ground for humpback whales, presumably from the little-studied Area VI population. The relationship of humpbacks in this region to those in adjacent tropical areas remains largely unknown, although recent matches between the Cook Islands and both Tonga and French Polynesia indicate some movement through Oceania.

KEYWORDS: HUMPBACK WHALE; SOUTH PACIFIC; COOK ISLANDS; STOCK IDENTITY; SURVEY-VESSEL; PHOTO-IDENTIFICATION; BREEDING GROUNDS

INTRODUCTION

Humpback whales (*Megaptera novaeangliae*) are widely distributed throughout the oceans of the Southern Hemisphere. Traditionally, populations of baleen whale species have been divided into six management units, termed Areas I to VI[1], although knowledge of actual stock boundaries is in most cases inconclusive (Donovan, 1991). Humpback whales from all six Areas feed in the circumpolar waters of the Antarctic, and migrate to a variety of distinct breeding grounds in tropical waters to the north (Kellogg, 1929; Mackintosh, 1942; Chittleborough, 1965). The most recent view of the IWC (International Whaling Commission) Scientific Committee on the feeding and breeding grounds of humpback whales in the Southern Hemisphere is given in IWC (2001).

Most of the information concerning the biology of humpbacks from these areas has come from 20th century commercial whaling catches, which were extensive throughout the Southern Hemisphere. However, current knowledge concerning the occurrence, distribution and population identity of humpbacks varies considerably by Area. Areas IV and V, which include (respectively) the western and eastern coasts of Australia, are relatively well studied as a result of thoroughly documented coastal whaling, as well as more recent investigations of living whales (Chittleborough, 1965; Dawbin, 1966; Abernethy *et al.*, 1992; Bannister, 1994; Paterson *et al.*, 1994; Brown *et al.*, 1995). In contrast, very little is known about the humpbacks that inhabit Area VI, the boundaries of which extend from the equator to the margins of the Antarctic continent from 120° to 180°W.

Within Area VI lie the Cook Islands, a group of islands and atolls scattered over approximately 800,000 square miles of the southwestern South Pacific (Figs 1 and 2). Little or no whaling has taken place in this region during the 20th century and records of earlier (historical) catches there are sparse. Except for occasional opportunistic observations (e.g. Leatherwood *et al.*, 1991), there have been no field studies of cetaceans in the area. Consequently, nothing is known about the biology or behaviour of humpback whales in the Cook Islands group. This paper reports survey results from the waters off Palmerston Atoll, Aitutaki and Rarotonga in the Cook Islands and suggests that this region represents a mating and calving area for humpbacks from the Area VI population.

MATERIALS AND METHODS

Study area

The Southern Cook Islands (Fig. 2) include nine islands or atolls between latitudes 18°S and 22°S. To date, this survey has been focused on three: Palmerston Atoll, a 30 mile^2 atoll lying at 18°04'S, 163°10'W on the northwestern margin of the Southern Cook group; Aitutaki, roughly 200 n.miles east of Palmerston; and Rarotonga, roughly 270 n.miles ESE of Palmerston. Since all three islands are the surface peaks of large seamounts, the seabed around the islands rapidly drops to abyssal depths exceeding 4,000m. Palmerston consists of small areas of land on the margin of a cratered lagoon that is protected by a barrier reef system. Surface water temperatures around Palmerston and Aitutaki average approximately 26°C with little seasonal variation. Surface water temperatures around Rarotonga are slightly cooler, averaging 25°C. Local weather is dominated by often strong easterly trade winds; thus, rough seas and large swells are common.

Study period and survey methods

Surveys of the Palmerston area were conducted from 19 September to 3 October 1998 and 4 October to 17 October 1999. Surveys off Aitutaki were conducted from 26 July to 11 August 1999. Surveys off Rarotonga were conducted from 17 August - 7 September 1999. Surveys took place on

[1] Some early workers, notably Mackintosh (1965) applied the word 'Group' to humpback whales, whereas 'Areas' has been used to represent common geographical boundaries for all Southern Hemisphere baleen whales, apart from Bryde's whales (see discussion in Donovan, 1991). We use 'Area' here.

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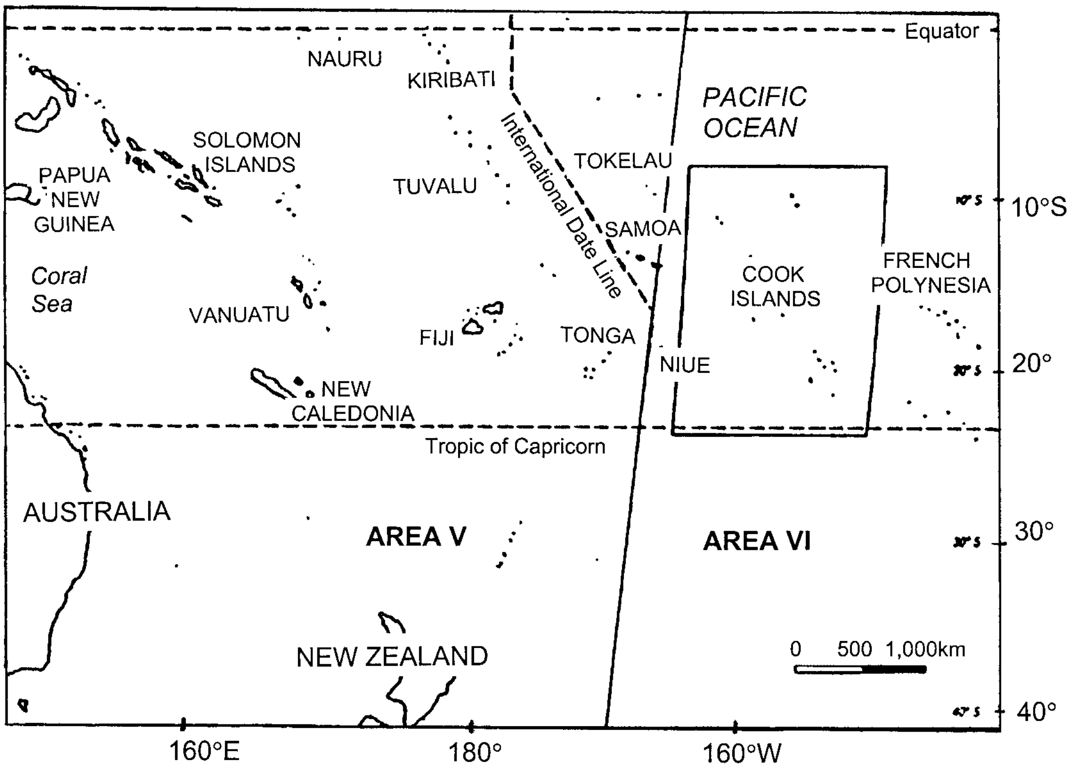

Fig. 1. The Pacific Ocean.

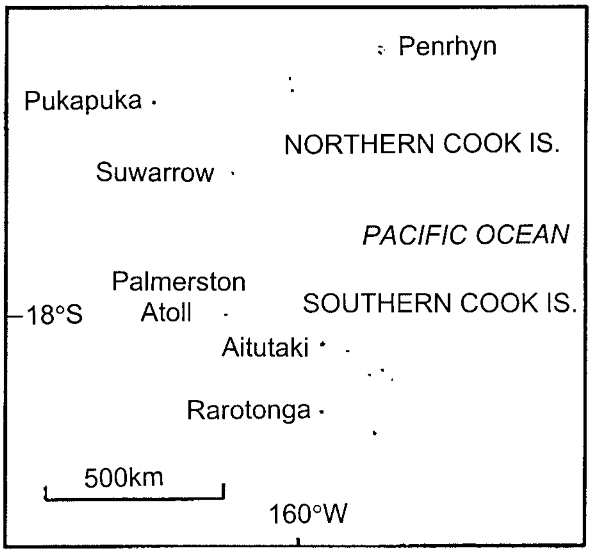

Fig. 2. The Cook Islands.

all days in which wind conditions (< 30 knots) permitted the operation of small (4-5.5m) aluminium or fibreglass boats powered by outboard engines ranging from 15hp to 50hp. Although attempts were made to cover all areas around the islands, weather conditions and the nature of the platform precluded the use of a systematic survey protocol. Most observations were made on the western side of the islands, where there was sometimes a small lee from the trade winds. There was no *a priori* selection of whale groups of a particular size or type to approach; generally, the vessel proceeded to the nearest sighting.

When humpback whales were sighted, the following data were recorded: time, location (relative to the islands), group size, group class and behaviour. Group class categories included non-singing singletons, singers, pairs, non-competitive trios, mother/calf pairs, mother/calf/escort trios and competitive groups. The latter were defined as involving three or more whales, with clearly recognisable group structure and occasional agonistic behaviour (Tyack and Whitehead, 1983; Baker and Herman, 1984; Clapham *et al.*, 1992). All single whales were approached and a hydrophone was used to determine if they were singing. All data were recorded using *Sony* micro cassette recorders and later transcribed to data forms.

Whenever possible, humpback whales were individually identified using photographs or videotape recordings of natural markings. In particular, the pattern on the ventral surface of the flukes was used (Katona and Whitehead, 1981), as well as other variable features visible either underwater or from surface observations. Photographs were taken with a 35mm camera equipped with a telephoto lens, recording data back, power winder and 400 ISO colour slide or black and white print film. Video observations were recorded using 3-chip mini-DV camcorders equipped with marine housings. Still video frames were captured with an *Apple* G3/300 computer using a Radius Moto-DV digital capture board.

Sloughed skin samples were collected from the water column in close proximity to the whales (Clapham *et al.*, 1993; Valsecchi *et al.*, 1998). Samples collected in 1998 were stored in a saturated salt solution for subsequent genetic analysis.

Samples collected in 1999 were stored in a solution of saturated sodium chloride and 20% DMSO. Humpback whale songs (Payne and McVay, 1971) were recorded using an HTI hydrophone and either a DAT recorder or a mini-DV camcorder.

In addition to the work at Palmerston in 1998, a one-day survey was conducted on 6 October at the island of Aitutaki. Observations were made from a 10m aluminium fishing vessel equipped with an inboard diesel engine. Opportunistic

Table 1

Survey hours and humpback whale sightings, by day and group class, off Palmerston, Aitutaki, and Rarotonga in 1998 and 1999. Group class abbreviations: SN singleton, SI singer, PR pair, TR non-competitive trio, MC mother/calf, MCE mother/calf and escort, CG competitive group. Singers heard but not seen are not included in Sightings or Group Class columns.

Location	Dates (No. of survey days)	Survey hours	Sightings		Group class							Mean group size	Song heard
			Groups	Whales	SN	SI	PR	TR	MC	MCE	CG		
Palmerston	18 Sep. - 6 Oct. 1998 (13 days)	41.3	19	36	2	4	7	3	2	0	1	1.77 SD=0.77, *n*=19	8 of 13 days
Aitutaki	26 Jul. - 11 Aug. 1999 (11 days)	52.9	4	7	0	1	2	0	1	0	0	1.75 SD=0.50, *n*=4	4 of 11 days
Rarotonga	17 Aug. - 7 Sep. 1999 (12 days)	56.5	19	28	5	5	9	0	0	0	0	1.5 SD=0.51, *n*=19	9 of 12 days
Palmerston	4 Oct. - 17 Oct. 1999 (12 days)	61.4	8	12	4	0	3	0	1	0	0	1.5 SD=0.53, *n*=8	11 of 12 days
Total	48 days	212.1	50	83	10	11	21	3	4	0	1	1.66 SD=0.62, *n*=50	n/a

sightings were also made *en route* from Rarotonga to Palmerston and back, aboard the 86m cruise ship *World Discoverer*.

While in the Cook Islands, local fishermen, naturalists and other individuals were interviewed regarding sightings of humpback whales in the region. The sighting records of the Cook Islands Natural Heritage Trust, which began a whale-sighting network in the Cook Islands in 1991, were also examined. Sighting forms originally developed by the Trust were distributed to field workers of the Cook Islands Fisheries Ministry to document whale sightings throughout the region.

RESULTS

Humpback whale occurrence

An overall summary of effort, sightings and group characteristics is given in Table 1. In total, 83 humpback whales were observed in 50 groups. Summary details are provided below for each area.

1998 Palmerston and Aitutaki

Thirty-six humpback whales (in 19 groups, mean group size 1.77, SD = 0.77) were recorded over 13 days (41.3 hours) from 19 September to 3 October 1998. These included six humpbacks observed during the one-day survey at Aitutaki, and three *en route* to or from Rarotonga.

1999 Aitutaki

Seven humpback whales (in 4 groups, mean group size 1.75, SD = 0.5) were recorded over 11 days (52.9 hours) from 26 July to 11 August 1999.

1999 Rarotonga

Twenty-eight humpback whales (in 19 groups, mean group size 1.5, SD = 0.51) were recorded over 12 days (56.5 hours) from 17 August to 7 September 1999.

1999 Palmerston

Twelve humpback whales (in 8 groups, mean group size 1.5, SD = 0.53) were recorded over 12 days (61.4 hours) from 4 to 17 October 1999.

At all three islands in 1999, humpback whales were found in a wide range of depths, including close to the reef, along the 'wall' and in abyssal depths away from the island. Because of rough weather, surveys could not be conducted more than about three miles from any of the islands, but at this distance the water depth exceeded 1,000m. Singers were observed in both shallow and deep areas. Distinct classes of whales were sighted, including non-singing singletons, singers, pairs, and mother/calf pairs; however, no non-competitive trios, mother/calf/escort trios or competitive groups were observed in 1999. Although the surveys were not designed to quantitatively estimate whale density, no trend in local abundance was evident over the study period.

Sample and data collection

Individual identification

Although analysis is ongoing, 31 humpbacks have been individually identified from photographs or frames captured from digital videotape to date (20 November 1999). Ventral fluke photographs were obtained for 20 of the 31 identified whales.

Of the 31 whales identified so far, all but five were sighted once. The exceptions were: (1) a whale photo-identified on 21 September 1998 off Palmerston and resighted ten days later on 1 October; (2) a whale photo-identified on 19 August, 1999 off Rarotonga and resighted four days later on 23 August; (3) a whale photo-identified on 26 August, 1999 off Rarotonga and resighted four days later on 30 August; and (4) a pair of whales each photo-identified on 27 August, 1999 off Rarotonga and resighted the next day, 28 August. To date no whales photo-identified in 1998 have been re-identified in 1999 photographs.

Skin samples

Seven sloughed skin samples were collected in 1998, and 22 were collected in 1999. These have been sent for analysis to the Ecology and Evolution Group at the University of Auckland (New Zealand), where DNA will be extracted and shared with other institutions for regional comparison purposes.

Song recordings

In 1998, approximately 4.1 hours of song recordings, covering a minimum of 11 full song cycles, were collected on six different days. Recordings ranged in length from 7 to 43min. During the one-day survey at Aitutaki, 1998, 28 minutes of song were recorded. In 1999, approximately 11.5

hours of song recordings were collected on 12 different days at Aitutaki, Rarotonga and Palmerston. No analysis has been conducted on any of these recordings to date.

Reports from elsewhere in the Cook Islands

Since 1991, the Cook Islands Natural Heritage Trust has distributed whale posters and sighting forms in various places throughout the region. Humpbacks are regularly reported to the Trust (primarily off Rarotonga) from July through November, and a pair of humpbacks was reported off Rarotonga in February 1991. Sighting reports and interviews with local individuals during the present study indicated that humpback abundance peaks between August and October. Cow-calf pairs and larger groups were also reported. Although species identifications are not easy to confirm, it is probable that most large whales seen in the coastal waters of the Cook Islands during the austral winter are humpbacks. However, it is possible that some sightings represent sperm whales (*Physeter macrocephalus*) or Bryde's whales (*Balaenoptera edeni*).

DISCUSSION

The results of this survey indicate that the Southern Cook Islands represent a calving ground for humpback whales during the austral winter. This is strongly suggested by the presence of mothers with calves in the area (both in our observations and in local sighting reports); some of our observations have involved very small calves with the grey, wrinkled skin typical of newborns. The sightings and acoustic detection of many singers, as well as the observation of a competitive group, further indicate that the area serves as a mating ground, since both singing and competitive behaviour have been strongly linked to courtship (Tyack, 1981; Tyack and Whitehead, 1983; Baker and Herman, 1984; Clapham *et al.*, 1992). It is likely that humpbacks at present use much or even the entire Cook Island region for calving and mating, although more work is required to confirm this belief.

The Cook Islands do not appear to have ever been a major site for humpback whaling. Maps compiled by Townsend (1935) from American whaling logbook data show only three records of humpbacks in the vicinity and it seems likely that these whales were encountered opportunistically by vessels *en route* to more established grounds at Tonga or elsewhere in the southwestern Pacific region. Documentation of local shore-based whaling in the Cook Islands is sparse, although there are reports of whales taken by natives at Rarotonga. That the focus of these local catches was probably the humpback whale is suggested by a local tradition that the flowering of the Ngatae (Indian Coral) tree during July represented a cue for local whalers to prepare boats and equipment for the arrival of the first whales (McCormack, 1990); this coincides with the timing of the humpbacks' migration into Cook Island waters. The other plausible target species, the sperm whale is much less seasonal in its occurrence.

Future work in this area should involve more intensive photographic and genetic sampling of humpback whales over a longer time period. The choice of the September/October period for this exploratory study was dictated solely by the availability of transportation to Palmerston. Elsewhere in the Southern Hemisphere (including Tonga), humpback whale abundance in breeding areas peaks in late August or early September (Dawbin, 1966; Abernethy *et al.*, 1992), and there is no reason to believe that Area VI whales follow a different trend. However, Chittleborough (1965) found peak abundance on the southward migration at 28°S off eastern Australia in late August, which would imply an earlier peak on the breeding grounds.

The population identity of the humpbacks in the region remains to be established. It is likely that they are a component of the Area VI stock, which is believed to feed on summering grounds in Antarctic waters to the south. The suggestion that humpbacks range through much of Oceania during winter is indicated by preliminary comparisons among photo-identification catalogues from several study sites in this region; these comparisons have revealed a match between the Cook Islands and Tonga, as well as between the Cook Islands and French Polynesia (Garrigue *et al.*, 2000). Further resolution of the extent of this movement will be resolved only through collection and comparison of additional photographic or genotypic individual identification data. As Cawthorn (1995) has noted, although Townsend's (1935) plotting of humpback catches in the Tongan Islands region suggests a widely dispersed breeding ground, re-examination of a subset of logbooks indicates that the great majority of catches were made in a narrowly defined area within 30 miles of specific islands.

Of the various island groups in the southwestern South Pacific, Tonga has been the focus of most recent work; Tonga lies in the eastern portion of Area V, some 600 miles west of Palmerston. The reported lack of recovery of humpbacks at Tonga (Abernethy *et al.*, 1992) contrasts with high estimated rates of increase of humpbacks off eastern and western Australia (e.g. Bannister, 1994; Paterson *et al.*, 1994). This suggests that either these two regions host separate populations or that much of the maternally transmitted fidelity (which led whales to return to the Tongan breeding area) has been lost through whaling. Additional support for the existence of separate stocks in the eastern and western portions of Area V comes from analysis of humpback songs, which have often been used as indicators of population mixing (see Payne and Guinee, 1983). Helweg *et al.* (1998) found distinct differences in songs recorded at Tonga compared to those from eastern Australia, Kaikoura (New Zealand) and New Caledonia.

To date, genetic results have been inconclusive with regard to population identity. Using mitochondrial DNA, Baker *et al.* (1994; 1998) confirmed the division between humpback populations in Areas IV and V, but the number of samples from Tonga was too small to test for significant division between this area and the western portion of Area V. However, the authors noted that the occurrence of non-shared haplotypes between Tonga and eastern Australia might indicate some division; resolution of this issue awaits analysis of additional samples from Tonga.

The abundance and population status of the whales from the Cook Islands are also unknown. Although no major whaling on humpbacks has ever occurred in the tropical portions of Area VI, large catches were made in the high-latitude feeding grounds of this management area (and that of eastern Area V); among these were substantial illegal takes by the USSR (Zemsky *et al.*, 1997; Yablokov *et al.*, 1998), including almost 13,000 animals taken in a single season (1959/60). As such, it is likely that the Area VI population was heavily depleted by commercial whaling; however, whether the number of whales observed in the Cook Islands reflects this depletion, or whether the major breeding concentration of this stock lies elsewhere, is unclear. Investigations of the current status of this population are clearly needed; however, obtaining reliable estimates of abundance from this region will not be easy, since working conditions are likely to be difficult in both high- and low-latitude portions of the whales' range. In the Cook Islands, the persistent strong trade winds and lack of substantial landmasses (to provide a lee) complicate the gathering of samples, photographs and data, and this problem is likely to be encountered in other island groups at similar latitudes. Assessment of this population's status and structure will require a coordinated effort by researchers in several locations.

In many locations where humpback whales have been studied using photo-identification, ventral fluke and other pigmentation patterns vary considerably from all white to all black (e.g. Katona and Whitehead, 1981; Baker *et al.*, 1986; Allen *et al.*, 1994). However, as is the case for whales in Areas IV and V (Kaufman *et al.*, 1987; Rosenbaum *et al.*, 1995), the ventral colouration of the humpbacks off Palmerston appears heavily biased towards white. In our study, 17 (85%) of the 20 identified individuals had all-white flukes; the remaining three flukes were one Category 2 and two Category 3, as defined by Rosenbaum *et al.* (1995).

The resulting reduction in variability relative to that of humpbacks in many other areas complicates recognition of individuals from ventral fluke photographs. Additional features elsewhere on the body are visible during underwater observations, and many of these were used to identify individuals in this study. However, the lack of a single standardised, highly variable feature (such as the fluke pattern) and the need for underwater observations, compromises the utility of photographic identification in this region. Although this method will be continued in future work in the area, it is recommend that biopsy-based genotyping with microsatellite DNA (Palsbøll *et al.*, 1997) also be used to identify individual humpback whales in the South Pacific. Biopsy samples also provide a wealth of data for genetic analysis, and can be used to easily determine the sex of each sampled whale (Bérubé and Palsbøll, 1996).

Future work

The intention is to return to the Cook Islands for at least four more humpback breeding seasons to determine population identity. The focus will be on collecting photo-identification data, skin biopsies, song recordings and behavioural data for contribution to a recently undertaken synoptic survey of humpbacks in the tropical South Pacific (Garrigue *et al.*, 2000). The survey will involve comparison of genotypic and photographic humpback samples collected in Eastern Australia, New Zealand, New Caledonia, Tonga, the Cook Islands and French Polynesia.

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A breeding area for humpback whales (*Megaptera novaeangliae*) off Ecuador

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ABSTRACT

A photo-identification study of humpback whales (*Megaptera novaeangliae*) was conducted between 1996 and 1999 in the Machalilla National Park off mainland Ecuador. This paper compares the results obtained with those from known breeding grounds for humpback whales to determine whether the area represents a breeding area for this species. Factors considered included: seasonality in abundance; population structure (including cow-calf pairs and escort whales) in the breeding area; presence of singers; and occupancy and residence times. It is concluded that the area does represent a breeding ground but the relationship of the animals using this area with those using other areas of the eastern tropical Pacific (and the Antarctic feeding grounds) requires further work. The paper also presents a preliminary estimate of abundance (405, 95%CI 221-531) for the years 1998/1999 using the Chapman-modified Peterson method.

KEYWORDS: HUMPBACK WHALE; SOUTH AMERICA; PACIFIC OCEAN; BREEDING GROUNDS; PHOTO-ID, MARK-RECAPTURE; SITE FIDELITY

INTRODUCTION

Southern Hemisphere humpback whales (*Megaptera novaeangliae*) migrate from their feeding grounds in Antarctic waters to the tropics where they reproduce in the austral winter (Matthews, 1937). On the breeding grounds, humpback whales mate, calve and feed little or not at all (e.g. Chittleborough, 1965). Mackintosh (1942; 1965) recognised six stocks distributed around the Antarctic continent during the austral summer. During the winter, each stock migrates towards the Equator to its own coastal or insular breeding ground in tropical or near-tropical waters. Known breeding grounds in the Southern Hemisphere are found off Africa (Rosenbaum *et al.*, 1997), Australia (Chittleborough, 1965), the southern Pacific islands (Dawbin, 1966; Hauser *et al.*, 2000) and South America (Winn and Reichley, 1985). The most recent review of Southern Hemisphere humpback whale feeding and breeding grounds is given in IWC (2001). There is little information available on the distribution of reproductive areas or on the movement of humpback whales in the eastern tropical Pacific. Such information is essential for determining the abundance of this particular stock and to monitor any possible recovery of the species, as has been documented elsewhere (e.g. see IWC, 2001).

The only well known reproductive area for humpback whales in the eastern tropical Pacific is around the Gorgona Islands in Colombia. Estimates for this population range between 170-450 animals (Flórez-González, 1991) and re-sightings with Antarctic humpbacks have confirmed that these animals migrate from Antarctic waters (Stone *et al.*, 1990). Humpback whales have also been sighted around Coco Island in Costa Rica (Acevedo and Smultea, 1995), Panama (Flórez-González *et al.*, 1998) and the Galapagos Islands (Merlen, pers. comm.), although it is not known whether these areas are used for reproduction.

Humpback whales are sighted off the Ecuadorian mainland in the marine area of the Machalilla National Park from June to September (Scheidat *et al.*, 1997). Within the last five years, a small whalewatching industry has developed in the fishing village of Puerto Lopez. Flórez-González *et al.* (1998) suggested that the humpback whales seen off the Ecuadorian coast only pass through the area while migrating to Colombia or possibly use the whole eastern tropical Pacific as a wintering ground, rather than being confined to a specific breeding site off Ecuador.

Humpback whale reproductive areas are characterised by certain oceanographic features, such as shallow waters with preferably banks of less then 60m (Whitehead and Moore, 1982). The water temperatures of humpback whale breeding grounds range from the coldest waters of 19-20°C in the Bonin Islands (Japan) to the warmer temperatures of 24-28°C in the West Indies (Naughton, 1997). In such areas, humpback whales exhibit behaviour associated with reproduction, such as aggression between males that compete for sexually mature females (Baker and Herman, 1984) and the presentation of typical ‘songs’ (Tyack, 1981). Young calves are also observed at such sites. The primary aim of this paper is to determine if the area of the Machalilla National Park is a breeding ground for the humpback whales of the South Pacific.

METHODS

Study area

The study area is a large bight on the continental shelf approximately 25 n.miles long and 20 n.miles wide. The maximum depth is 200m, with shallow areas of 10-30m around the Isla de la Plata, the Cantagallo shallow and along the coast. The sea bottom consists of sand, rocky areas and coral reefs (Ayón, 1988). The Isla de la Plata, as well as the area of the Cantagallo shallow, is characterised by sand and coral reefs (Anon., 1997). Beyond Isla de la Plata the continental shelf drops away rapidly to depths of more than 3,000m (Fig. 1).

The study area is influenced by several large current systems. During the dry season (June to September), the Ecuadorian Countercurrent comes from the west between 4° and 10° north and is deflected by the continent where it splits

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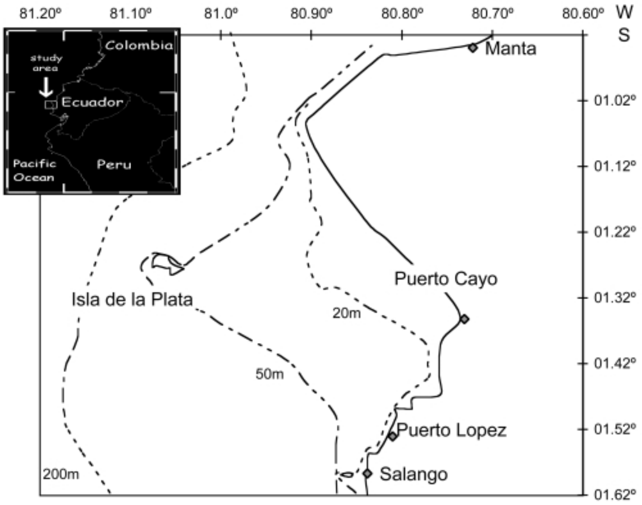

Fig. 1. Map of the study area.

into the North Ecuadorial Current and the South Ecuadorial Current. The Humboldt Current from the south, forms the Ecuadorial Front when it meets the South Ecuadorial Current. During the dry season this front lies in the study area between 1° and 5° south and is characterised by high quantities of nutrients (Anon., 1997). These waters have high zooplankton and fish densities and support a local fishing industry, suggesting that the bay exhibits a level of primary productivity that is atypically high among tropical marine systems (Anon., 1997). Prevailing winds are southwesterly trade winds.

Data collection

Humpback whales can be individually identified by unique features in the coloration, shape and scarring pattern of the ventral side of their flukes (Katona and Whitehead, 1981). Photos of humpback whale flukes were taken in the study area during the austral summer from 1996 to 1999. Within any season, whenever possible, daily trips were undertaken for the purpose of photo-identification. Effort in 1996 concentrated on the months of August and September, with a total of 28 boat trips conducted. In 1997, the field season did not start before late-July and ended in September and 36 trips were made. In 1998 and 1999, sampling took place from June-September with 40 and 42 trips, respectively. For the analyses of group composition only the year 1999 was used, as oceanographic conditions made 1997 and 1998 atypical years (see Discussion).

For analyses of relative abundance, behaviour and group sizes, only the 1999 data were used. In 1999, effort took place from 10 June to 18 September, covering the widest time period available to this study and thus potentially giving a better idea of the migration pattern of the whales.

Photo-identification was carried out from whalewatching vessels leaving from Puerto Lopez or Puerto Cayo travelling to the Isla de la Plata. The boats were 6-8m long with 75 or 115hp engines. Photos were taken from the roofs of the vessels at a height of about 2m with a 35mm single-lens reflex camera equipped with either a 300mm lens or 70-210mm zoom lens and using 200 ASA colour slide film.

For each sighting of a whale or group of whales, the time, GPS position, behaviour, group composition, group size and the pictures taken from each animal were recorded. In the later analyses, all fluke photographs were judged to be of either good, fair or poor quality. Good and fair quality photographs showed at least 50% of the fluke at an angle sufficiently vertical to distinguish the shape of the flukes' trailing edges. For this study, poor-quality photographs were deleted from the dataset. The best photograph of a fluke taken during one sighting was assigned an identification number. During the matching of fluke photographs, a whale that was identified on more than one occasion was assigned an animal number, allowing us to reference all fluke identifications of that individual. All fluke photographs of good or fair quality were scanned with a slide scanner and stored in a data file together with the additional information available for that sighting.

To estimate population size in the Machalilla National Park, Chapman's modification of the Petersen method for closed populations was used (Seber, 1973). The 95% Confidence Interval was approximated according to Sutherland (1996). The main assumptions underlying Petersen's method are: (1) the population is closed, i.e. no whales leave or enter the population before the second sample; (2) during a sampling period all whales have the same probability of being sighted, photographed and identified; and (3) fluke patterns do not change between sample periods and each pattern can be identified. The general applicability of these assumptions to photo-identification data have been discussed extensively elsewhere (e.g. Hammond, 1986). An open population model such as the Jolly-Seber model was not used because a small sample size can lead to high variability and imprecision.

A hydrophone was deployed on a total of 12 occasions to listen for humpback whales. As the study was conducted from whalewatching vessels, individual whales could not be followed for identification or their position determined.

Definitions

Relative abundance

This was defined as the number of whales per hour searched by the whalewatching vessel. The search effort only includes the time actively searched by the researcher and does not include the time spent with a sighting.

Sighting

A sighting was defined as either a lone whale, or a group of whales where members of the group were within 100m of each other and generally moving in the same direction and coordinating their behaviour (Mobley and Herman, 1985).

Calf

A calf was defined as an animal in close proximity to another whale (less than one whale length separating the pair), and estimated to be less than 50% of the length of the accompanying animal.

Occupancy

Occupancy was estimated as the period, in days, between the first and last sighting of a whale in a season.

Surface active behaviour

All surface active behaviour, agonistic behaviour and possible breeding behaviour was pooled together into one category. Surface active behaviour included breaches as well as flipper or fluke slapping and waving. Agonistic behaviour included head lunges, breaches, fluke and flipperslaps that were directed towards another whale (Tyack and Whitehead, 1983; Baker and Herman, 1984; Winn and Reichley, 1985).

Behaviour thought to be associated with breeding was defined as belly flippering, rolling or 'headstands' (Tyack, 1981).

RESULTS

Relative abundance

In 1999, whalewatching operators observed the first humpback whales on 16 May. The relative abundance calculated from the transects varied from a minimum average of 0.3 animals/hour on 17 June to the maximum of 7.2 animals/hour on 23 July. Fig. 2 shows an increase in whale abundance in mid/late June and a decrease of abundance at the beginning of September.

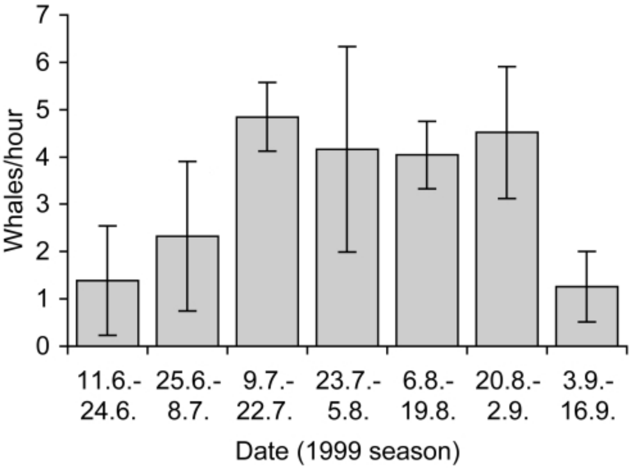

Fig. 2. Seasonal changes in relative abundance of humpback whales throughout the 1999 season. Relative abundance is represented by the average number of whales seen per hour in each two-week period (error bars represent SD).

Group size

In 1999, a total of 109 sightings was made (254 whales), with the mean group size being 2.33 (SD = 1.05). The modal pod size was two. Pod sizes varied between one and a maximum of eight animals. Mean group size increased from 2.11 in early season (10 June to 8 July), to 2.29 in mid-season (9 July to 19 August) and to 2.46 in late season (20 August to 18 September) (Fig. 3). The differences between the distribution of group sizes from early, mid- and late season were not significant ($\chi 2$ - test: $p > 0.1$).

Presence of calves

The first calf sighting during this study was made on 22 July 1999. On 5 August 1999, a calf was observed that was estimated to be less < 5m in length and which had a dorsal fin that was doubled over, indicating a recent birth. In July 1995, the captain of the National Park vessel had observed the birth of a humpback whale calf close to the Isla de la Plata (R. Gonzalez, pers. comm.). In 1998, a humpback whale calf was caught by a fisherman close to the coast (at about 80°49'W and 01°24'S). It could not be determined whether the calf was already dead when caught or had died in the net.

The percentage of humpback whale sightings that included a calf increased from 7% in mid-season (9 July to 19 August) to 17% in late season (20 August to 18 September) (Fig. 3).

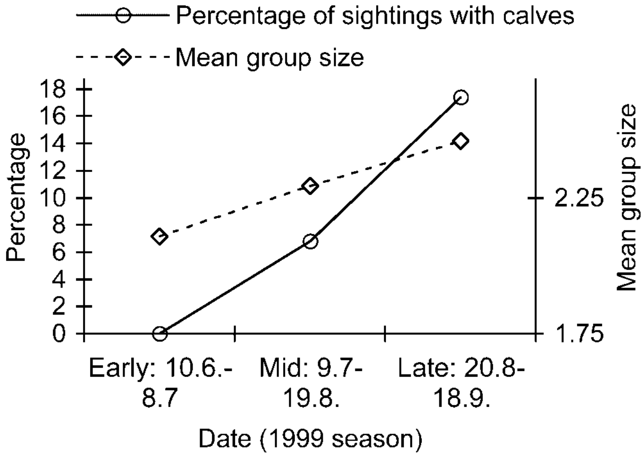

Fig. 3. Seasonal changes in mean group size and percentage of sightings with calves in the 1999 season.

For pods with calves, a group of two signifies a mother-calf pair alone. Larger-sized pods indicate that other adult whales known as 'escorts' (Herman and Antinoja, 1977) were accompanying the mother-calf pair. It was more common for a mother-calf pair to be seen in the company of other whales than to be seen alone and 61.5% of all sightings consisted of three or more animals.

Of all sightings with calves, the most common comprised triads of the mother, calf and an accompanying escort (46.1%); 15.4% were part of a group of whales of more than two adults and 38.5% were mother-calf pairs. Throughout the season the group size of pods with calves increased. During the two-week period from 6-19 August, all mother-calf pairs were accompanied by at least one other adult whale.

Surface active behaviour

Throughout the season, breaching as well as fluke and flipper slapping was observed. 'Tail breaches' used against other animals were seen on numerous occasions. Here, the rear third of the body was thrown out of the water and slammed sideways and downwards against the water surface. Fluke slaps and head lunges from one whale directed towards another and animals exhaling under water and creating bubbles, vocalising above the water ('trumpet blows') and breaching were also seen, as well as flipper slapping in close proximity to other whales. Other behaviours included belly flippering, spyhops, rolling and 'headstands'. On one occasion a humpback whale stayed in the 'headstand' position for up to 17 minutes before returning briefly to a horizontal position to breathe. A second whale in close proximity was observed to stay underwater, apparently pushing its head against the ventral side of the whale executing the headstand. This behaviour was observed from the shore continuously for three hours with the whale only returning to the horizontal position to breathe. The sex of the individual whales could not be determined.

Throughout the season the frequency of surface active behaviour increased. In the two-week period from 23 June to 5 August 1999, 67% of the sightings contained individuals that were engaged in surface active behaviour (Fig. 4). Towards the end of the season this percentage decreased to 38%.

On ten of the twelve occasions when a hydrophone was deployed, humpback whale songs could be heard.

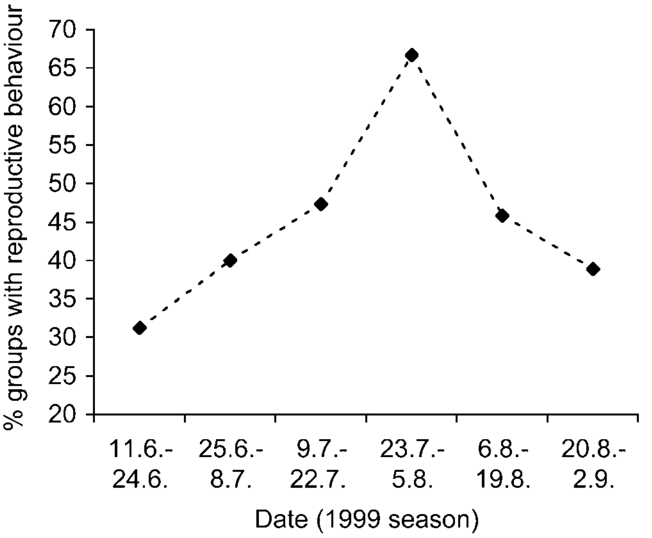

Fig. 4. Seasonal changes in frequency of surface active behaviour during 1999.

Table 1

Sighting history of individual whales seen between 1996 and 1999.

Whale ID	1996	1997	1998	1999
C96-8	X	X		
C96-10	X			X
C96-13	X		X	
C97-4		X	X	
C97-12	X	X	X	X

Annual return

Table 1 shows the number of animals that were identified individually. In total, fluke pictures of 209 individuals were taken. Of these, 116 were poor quality and were not considered in the analyses. A total of 93 different individual humpback whales was identified during the study years 1996 to 1999 using fluke identification. Of these, five different animals were re-sighted between years.

Within-season occupancy

Table 2 summarises data on effort and on occupancy of individual whales during the period 1996 to 1999. Observed occupancy of individuals ranged from 1 to 30 days; the mean occupancy for all whales observed in a year varied from 7-21.67 days, with an overall mean of 13 days. A total of 12 different whales were seen more than once in a year. In 1997, one individual humpback whale was first photographed on 26 August, then again on 31 August, 23 September and 24 September.

Table 2

Number of cruises made, maximum and mean occupancy (in days) of individuals for each year.

	1996	1997	1998	1999	All years
No. of cruises	28	36	40	42	146
Occupancy					
Mean	12.00	12.33	21.67	7	13
Maximum	28	29	30	17	30
SD	14.00	14.43	7.37	8.66	11.3

Table 3

Calculated population estimates using the Chapman's modified Petersen estimator (no replacement) between years.

	n_1	n_2	m_1	N	95% CI
1996-1997	29	14	2	149	80 - 380
1997-1998	14	28	2	144	78 - 385
1998-1999	28	27	1	405	221 - 531

Population estimate

Population size was calculated between years (Table 3) with Chapman's modified estimator for the Petersen model. Population estimates varied between 144 to 405 animals.

DISCUSSION

Evidence that the Machalilla National Park represents a breeding area

Seasonality in abundance

The relative abundance of humpback whales in the study area shows a typical breeding ground pattern - increasing relative abundance after the arrival of humpback whales in June, a peak in relative abundance from July to August and decreasing relative abundance with the onset of the southern migration in September. This is similar, for example, to the pattern observed for North Atlantic humpback whales (e.g. Mattila *et al.*, 1994). By contrast, if the area was merely along a migration route, one would expect to see a bimodal distribution with higher number of whales during the migration periods of June and September. This has been observed in other areas such as the west coast of South Africa (Best *et al.*, 1995) and off Brisbane in Australia, where peaks of abundance are found during the northward migration from June to July as well as during the southward migration from August to the end of October (Bryden *et al.*, 1990).

Population structure in the breeding area

Whaling data from the South Pacific suggest that the majority of the sexually mature males migrate toward the lower latitudes after the immature animals and late-pregnant females, arriving at the wintering grounds in late July. Non-pregnant females closely follow the mature males; presumably, these females make up the majority of that season's female breeding population (Chittleborough, 1958; Dawbin, 1997). Female humpback whales have their calves in the winter and, since the gestation period is about one year, mating must therefore occur during the same season (e.g. Mackintosh, 1942; 1965).

In the present study, about 60% of the sightings with calves were mother-calf pairs that were accompanied by one or more adult whales. A similar percentage was found by Mobley and Herman (1985) in the Hawaiian breeding grounds. By the beginning of August, the group size of sightings with calves increased to a modal group size of three. The escorts of mother-calf pairs are thought to be males seeking access to reproductively active females (Tyack, 1981; Clapham *et al.*, 1992), although the probability of post-partum ovulation leading to successful conception may not be high (Glockner-Ferrari and Ferrari, 1984; Corkeron *et al.*, 1994). The presence of adults whales around a new-born calf might also help to protect against attacks from killer whales (*Orcinus orca*). The authors observed such an attack in July 1997, when two adult male killer whales attacked a group of five humpback whales, one of them a calf, close to the Isla de la Plata. The calf showed an injury on it's fluke but appears to have survived. Such attacks have also been observed in the Colombian breeding ground (Flórez-González *et al.*, 1994).

Behaviour

The mean group size of humpback whale sightings increased from the end of July to the beginning of September, although this was not statistically significant. Such an increase can be explained in part by the presence of calves but also by the formation of competitive groups. Competitive groups and their behaviour were first described in detail by Tyack and Whitehead (1983) as well as by Baker and Herman (1984), who suggested that such groups consist of several adult males competing for sexual access to a single mature female. A variety of agonistic behaviour was observed which has been described in detail for humpback whales while in their breeding grounds (Tyack, 1981; Winn and Reichley, 1985; Clapham *et al.*, 1992).

Presence of singers

Humpback whale songs are a distinctive continuous sequence of vocalisations generally performed by males (Whitehead, 1985). Singing is almost never heard on the feeding grounds (Perkins and Whitehead, 1977; Clapham *et al.*, 1992) and research by Tyack (1981) off Hawaii relates singing to mate attraction; Frankel *et al.* (1995) suggest that the songs are a spacing mechanism between males. Although systematic acoustic research could not be conducted, the presence of songs does indicate that the study area is a reproduction ground.

Resightings

Five individuals were re-sighted between years and one animal was seen every year from 1996. Not only did individual humpbacks return to the study area, but re-sightings were also made within a given season. The maximum occupancy time observed in the study area was 30 days. However, not all pods in the study area were sampled every day and sample sizes are inevitably small. The estimates presented here can probably be considered as minimum times. The available data suggest that most whales spend a short period (up to five days) in the area, but around 10% spend more than two weeks in the study area. It may be that some whales established preferred ranges within the study area while others were relatively transient.

The occupancy times found for the Machalilla National Park are similar to those found in known reproductive areas. For example, in a study on Silver Bank (West Indies), where 9.1% of identified whales were sighted again in the same season, the greatest time between first and last sighting was 30 days and the mean period of residency of the whales was 8.52 days (Mattila *et al.*, 1989). The longest sighting interval reported by Baker and Herman (1981) was 44 days where an animal was first seen in Hawaii and then in Maui (a relatively long movement). They also reported resightings of a mother-calf pair over a 26 day period and whales were re-photographed at periods ranging from a few days to as long as 34 days. A study in Samana Bay, Dominican Republic (Mattila *et al.*, 1994), showed the largest time interval between identified whales within a season to be 33 days.

Relationship with other areas in the eastern tropical Pacific

Some humpback whales have been documented moving between breeding grounds, for example within the West Indies (Mattila *et al.*, 1994), between Hawaii and Mexico (Darling and Jurasz, 1983) and between Hawaii and Japan (Salden *et al.*, 1999). Salden *et al.* (1999) suggest that these wanderers are mainly males. Nevertheless, movement between wintering grounds is relatively rare compared to regional return (e.g. Baker *et al.*, 1985). However, within a larger reproductive area, such as the Hawaiian Islands, extensive movement of individuals does take place. Cerchio *et al.* (1998) showed that individual humpbacks, mostly males, can move between the Hawaiian islands of Kauai and Hawaii over short time periods. In the eastern tropical Pacific one humpback whale has been sighted in Colombia and Ecuador, but not in the same year (Flórez-González *et al.*, 1998). The distance between the Machalilla National Park and Gorgona Island is about 325 n.miles and could be travelled in about 10 days, at a speed of 220 n.miles per week (Dawbin, 1966). Therefore, it is possible that the Ecuadorian and Colombian humpback whales are part of a larger reproductive area in which some movement takes place.

Bravo *et al.* (1994) noted that humpback whales have been observed as early as mid-June in the Colombian breeding ground, with peak abundance between August and October and some seen as late as mid-December. If the Colombian humpback 'population' arrives in June in Colombia this could mean that at least part of the it passes through the Machalilla National Park during their northbound migration. A strong peak in relative abundance is apparent at the beginning of July, possibly indicating an overlap of these 'populations'. The season off the Ecuadorian coast is from mid-May to mid-October, with humpback whales rarely being sighted after the beginning of October, even though whalewatching tours go to the Isla de la Plata throughout the year and record sightings of cetaceans outside of the typical humpback whale season. It is therefore improbable that the whales from the Colombian population pass through the Machalilla National Park on their southward migration.

One possible scenario is that at the end of the reproductive season, the humpback whales off Colombia move west before starting south, possibly passing the Galapagos Islands where humpback whales are sighted from July to September. However, only a few individuals are observed there and no increase of sightings by month is apparent (G. Merlen, pers. comm.). Further research, to include the islands of Coco, Galapagos and the waters of Panama, is needed to understand the migration patterns of the humpback whales present in this area.

Preliminary abundance estimate

Mark-recapture models make a number of assumptions (e.g. see Hammond, 1986; Hammond *et al.*, 1990). The point estimates presented here for the Chapman-modified Petersen (closed population) model vary between 144 and 405 animals. One of main assumptions is that all animals have an equal capture probability. In 1997, only 12 new animals could be identified by their flukes, although the effort was as high as in other years (Table 1). The sea surface temperature in the Machalilla National Park during the dry season from April to September typically lies between 20°C and 24°C (Stevenson *et al.*, 1970). In 1997, due to the El Niño Southern Oscillation, sea surface temperatures in the study area were up to 10°C higher than in 'normal' years, taking local surface temperatures in 1997 up to 30°C (CPPS, 1999). It seems that either fewer humpback whales were present or that the animals changed their behaviour in a way that made them harder to see and photograph. A thorough analysis of the possible effect of El Niño will be the subject of a future paper. Given the problems with the 1997 data, we believe that the estimate of 405 animals (95%CI 221-531) for the years 1998 to 1999 represents the best preliminary abundance estimate for the humpback whale population in non-El Niño years. It should be noted that estimating population size from mark-recapture studied in breeding areas alone will generally result in a negatively biased estimate due heterogeneity in capture probabilities arising out of differences in sex/reproductive class (Smith *et al.*, 1999). Future combination of Antarctic catalogues as well as increased effort in Ecuadorian waters should provide a better estimate in the future.

CONCLUSION

The increase in reproductive behaviour and the observation of young calves, as well as the increase in relative abundance throughout the season and re-sightings of individual animals over several years, provides evidence that the area of the Machalilla National Park forms a reproductive area for humpback whales. However, data are lacking to determine if the area represents a distinct breeding ground or rather a preferred habitat for humpback whales that use a larger seasonal range in the eastern tropical Pacific. A comparison of the photo-identification catalogues of the different research sites in the eastern tropical Pacific as well as in the Antarctic feeding grounds is needed to increase our understanding of the migration routes and the distribution of breeding grounds. Genetic studies and song comparison should help clarify the stock identity of these humpback whales.

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Finding similar trailing edges in large collections of photographs of sperm whales

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ABSTRACT

The North Atlantic and Mediterranean Sperm Whale Catalogue (NAMSC 1.0) contains images collected via the cooperative effort of several individuals studying sperm whales in the North Atlantic and Mediterranean. The collection offers an important opportunity to test matching algorithms as an aid to photo-identification of individual sperm whales. Of the 2,081 photographs in the catalogue, 1,929 were of sufficient quality for photo-identification. The trailing edge of the fluke, an identifying feature, was extracted by an interactive method. Subsequently, the trailing edge was represented in a normalised form by an affine transformation. Left and right halves were processed separately. Using different methods, 489 matching pairs of photographs were found. Based on these confirmed matches, the power of several measures of similarity was compared. The measure of similarity calculated by cross-correlating the continuous wavelet transforms of the extracted contours was found to perform best in practice. No conclusive matches between photographs from different geographic locations were found.

KEYWORDS: PHOTO-IDENTIFICATION; SPERM WHALE; EUROPE; ATLANTIC OCEAN; TECHNIQUES

INTRODUCTION

Sperm whale researchers working in the North Atlantic and Mediterranean have collected a considerable body of photographic material from sperm whales. The first edition of the North Atlantic and Mediterranean Sperm Whale Catalogue (NAMSC) was published on CD in 1999 by the International Fund for Animal Welfare (IFAW) and the Centre of Environmental Science at Leiden University (CML). Each submitted photograph was archived with the year and place of observation, and the name of the contributor. The copyright of the photographs remains with the contributors. The contour of the trailing edge of the fluke is used for identification of individual sperm whales (Whitehead and Gordon, 1986; Arnbom, 1987). Some evidence has been gathered (e.g. Dufault and Whitehead, 1995; Childerhouse *et al.*, 1996) to show that changes in the contour of the trailing edge are limited and allow matching observations up to at least a decade apart. The NAMSC will continue to evolve as new images are submitted but even now the collection offers an important opportunity to test contour matching procedures.

Relatively small collections (<200 individuals) can be accessed using memory and visual inspection by an analyst, but some form of feature-based catalogue is needed to retrieve material from collections consisting of thousands of photographs. There are two general approaches to this: (1) by landmarking; (2) assigning a measure of similarity to a descriptor of the identifying features.

In landmarking, an observer assigns one feature out of a small set to a photographed individual. The photographs are subsequently stored in categories using the assigned feature as a key to the category. To match photographs, the observer only has to examine those photographs sharing the same feature stored in one category. Obviously, there is a trade-off between the resolution of the features and the size of the resulting categories. The method can be impressively effective, but may be susceptible to differences in personal interpretation of the identifying features. For example, two observers, or the same observer at two sessions, might assign different identifying features to the same individual and store photographs of one individual in different categories. Finding an incorrectly categorised item generally means re-examining the whole collection.

Methods based on mathematically derived measures of similarity between descriptors are insensitive to changes in human interpretation. However, while the human brain easily identifies two patterns as equal even if one of the patterns is transformed, designing a computer programme that equals this human ability has proved particularly challenging.

Both approaches have been applied in existing methods of automated photo-identification. Mizroch *et al.* (1990) uses a pure form of landmarking, while Hiby and Lovell (1990) apply similarity measure to mathematical descriptors. Whitehead (1990) uses a mixed form, applying a mathematical similarity measure to ascribed features.

Some progress has been made in identifying features from photos after affine transformation (Minh *et al.*, 1999; Tuytelaars and Van Gool, 1999), but these studies are limited to rigid features. The sperm whale fluke is flexible, and non-linear distortions, such as folding and bending, are superimposed on the linear transformations of roll, yaw and pitch, caused by the angle of the photograph. The fact that the identifying features are localised on the trailing edge, while the photographic projection is subject to non-linear distortion, makes the problem of automated matching of trailing edges a challenging one to address.

As a continuation of earlier work (Huele and Udo de Haes, 1998; Huele and Ciano, 1999) it was supposed that a measure of similarity between the wavelet transforms of two trailing edges would be less sensitive to non-linear distortions than a measure of similarity between the non-transformed trailing edges.

Ideally, the distribution of similarity measures of non-matching photographs would be completely disjunct from those of matching photographs. No such similarity measure was found and all measures produced false

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positives and false negatives. False positives, i.e. photographs representing two different individuals but having a high similarity measure, are easily discovered by visual verification. False negatives, i.e. photographs representing one individual but having a low measure of similarity, can only be found by going through all the material. Both make it more difficult to find matching photographs, by increasing the bulk of material that has to be examined by eye. The performance of the measures of similarity was compared both on the fraction of false positives and on the fraction of false negatives.

MATERIAL AND METHODS

The NAMSC contains 2,081 photographs, digitised by staff at IFAW. Most photographs are black and white, although 61 colour photos are included. All photographs were digitised and stored as JPEG files, with a mean file size of 52kb. Of the 2,081 photographs, 152 could not be used for individual identification for reasons of quality, resolution, angle, or because the photo did not show a fluke at all. Flukes photographed at the beginning of the dive, with the trailing edge pointed downwards, were also discarded. See Table 1 for a breakdown into years and locations.

No totally observer independent method was found to extract the trailing edge from the photograph in a satisfactory manner. Conventional edge detection methods extracted not only the edge of the fluke but often also the meaningless edges of waves and clouds; therefore, a semi-automated technique was developed, in which the analyst identified the two tips of the fluke plus the central notch by mouse clicking. An algorithm was chosen, based on the modulus maximus method described by Mallat (Mallat and Hwang, 1992; Mallat and Zhong, 1992), to extract an approximation of the trailing edge. The analyst can either accept this contour as correct or can indicate which area of the curve does not correspond to the contour by dragging the mouse to indicate that particular area. The algorithm subsequently refines the approximation and again the analyst can either accept this or indicate a new area of interest. This process continues until the analyst is satisfied with the extraction. The contour is then stored as a structure consisting of the x and y coordinates of the two tips, the central notch and the contour.

The central notch on the trailing edge is the major singularity in the signal and was found to overwhelm the information for the rest of the trailing edge. For this reason, both halves were processed separately. The left half and right half were represented by interpolation as 64 numbers each and were normalised by the affine transformation as described by Tuytelaars and Van Gool (1999) and Schodts and Vleugels (2000).

For both the contours of the left half and the contours of the right half, four measures of similarity were calculated:

(1) linear correlation between the contours;
(2) the maximum value of the cross-correlation between the contours, based on the argument that the contours might be shifted in phase due to noise in the extraction method;
(3) linear correlation of the wavelet transforms of the contour; and
(4) the maximum value of the cross-correlation of the wavelet transforms of the contour, based on the assumption that this measure would be relatively insensitive to linear and non-linear distortions of the contour.

The separate measures were combined in two different ways to calculate a measure of similarity for the total contour: (1) arguing from similarity, the measure was defined as $r1\_total = r\_left * r\_right$; and (2) arguing from dissimilarity, the measure was defined as $r2\_total = 1-(1-r\_left) * (1-r\_right)$.

As wavelet transformation, the bi-orthogonal wavelet 6.8 was chosen after some preliminary tests. The transformation results in a multi-resolution, two-dimensional representation of the trailing edge. Traditionally, the transform is depicted as an image, where the colours or shades of grey indicate the values (see Fig. 1).

Table 1

The number of photographs in NAMSC, per year and location, number of photographs suitable for matching, number of matches and number of identifiable individuals, per location.

	Andenes	Azores	Canaries	Dominica	Grenada	Jamaica	Mediterranean	Panama	Shetland	Greenland	Total
1984	-	1	-	15	-	-	-	-	-	-	16
1985	-	1	-	-	-	-	-	-	-	-	1
1986	-	-	-	-	-	-	-	-	-	-	0
1987	7	24	-	-	-	-	-	-	-	-	31
1988	14	156	-	-	-	-	-	-	-	-	170
1989	30	116	-	-	-	-	-	-	-	2	148
1990	48	133	-	-	-	-	-	-	-	8	189
1991	24	178	-	-	-	-	-	-	-	-	202
1992	25	-	-	-	-	-	-	-	-	-	25
1993	31	123	21	-	-	10	-	10	-	-	195
1994	30	126	-	-	-	-	39	-	-	-	195
1995	18	172	7	73	8	-	1	-	-	-	279
1996	53	161	3	26	-	-	2	-	-	-	245
1997	79	116	-	4	-	-	1	-	-	-	200
1998	65	113	-	-	-	-	3	-	-	-	181
1999	-	-	-	-	-	-	-	-	1	-	1
Undated	-	1	2	-	-	-	-	-	-	-	3
Total	424	1,421	33	118	8	10	46	10	1	10	2,081
Acceptable	378	1,322	33	117	8	10	41	10	0	10	1,929
Matches	80	297	45	17	2	0	47	0	0	1	489
Individuals	318	1,134	15	105	8	10	28	10	1	9	1,638

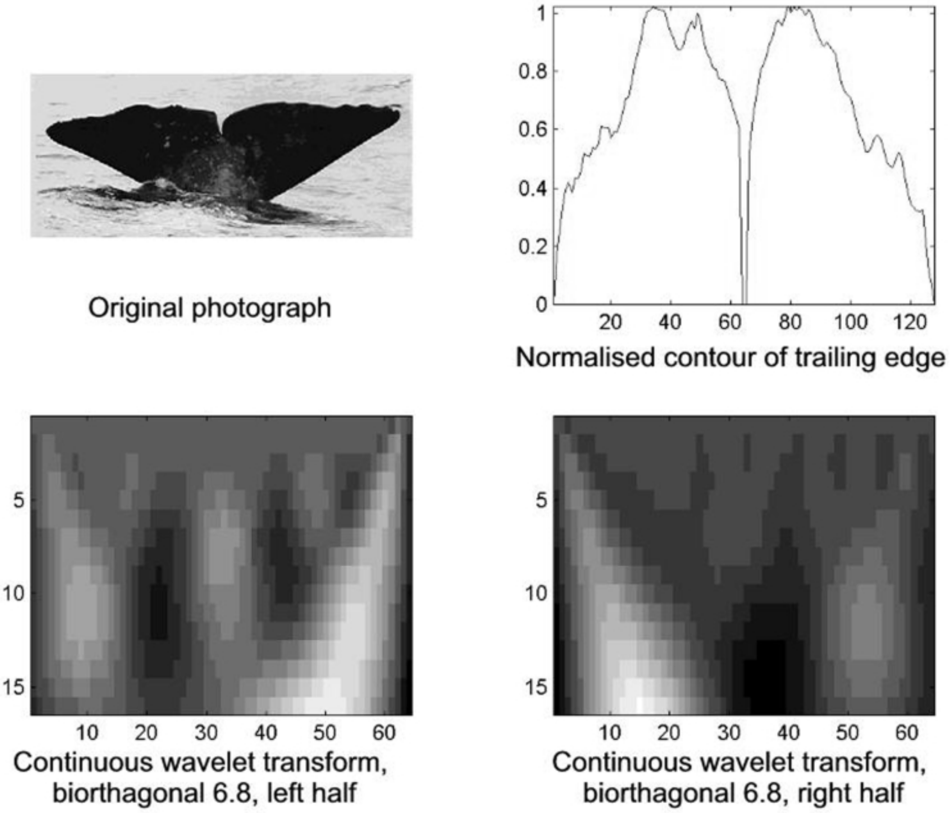

Fig. 1. The transformation of the trailing edge.

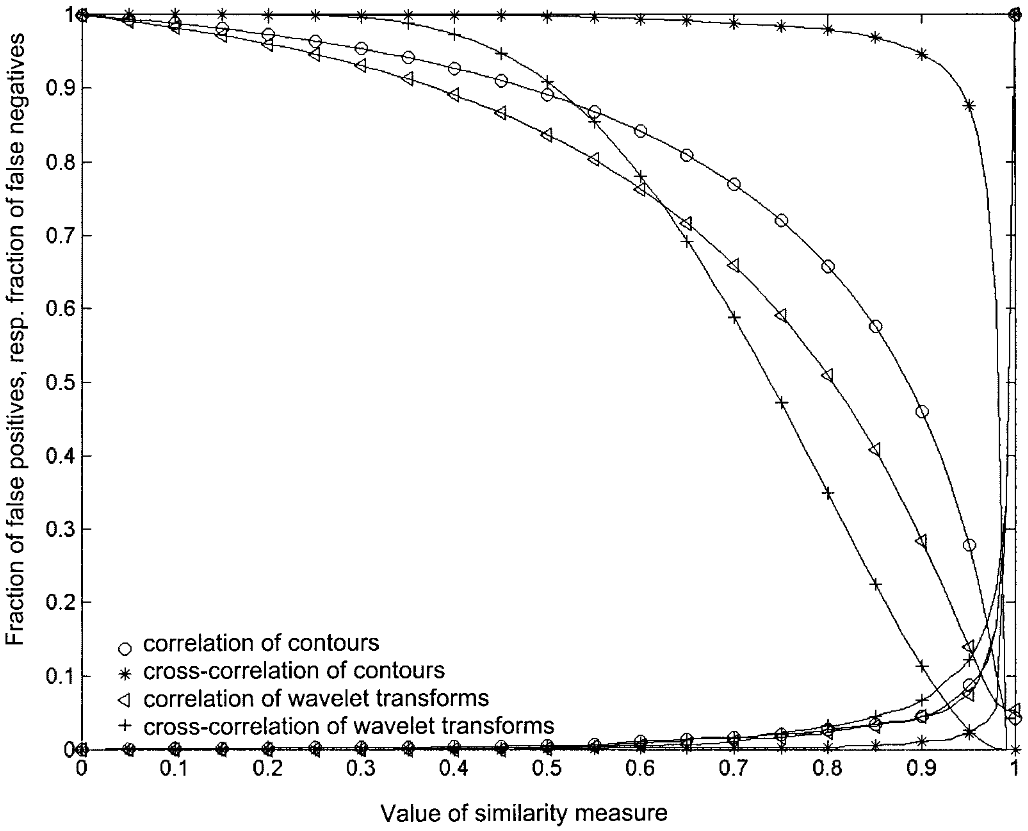

Fig. 2. Power of four measures of similarity: false positives and false negatives.

RESULTS

For the 1,927 photographs that were considered, 489 matches were found, counting one set of different photographs of one individually identified sperm whale as one match. Matches were confirmed by eye by at least two independent observers. No similarity measure, combined with a threshold value, separated all matching pairs from the non-matching pairs. In all cases, the measure of the total defined by *r_total = 1- (1-r_left) * (1-r_right)* was found to perform better than the measure calculated by direct multiplication. Likewise, the combined measure was found to perform better than the similarity measures of the separate halves.

Comparing the different measures of similarity, it was found that cross-correlating the contours produced the least false negatives (Fig. 2). However, this method caused many false positives, which made it difficult to find a true match in a sub-collection of sets having high measures of similarity. Cross-correlating the wavelet transforms led to a slightly higher number of false negatives, but discriminated more strongly on false positives. As sets of photographs always had to be examined by eye to be confirmed, the latter method proved more practical for choosing the 'nearest neighbours' as likely candidates.

Digitising and archiving the photographs is relatively time consuming. Once the photographs are in digital format, it takes about one hour to extract the contours of 100 photographs. Cross-correlating all 2,081 photographs against each other took eight hours of calculation time per level, on a 133Mhz Pentium machine with 128-Mb internal memory. It is estimated that scanning the 2,081 photographs and extracting the contours required about 80 hours. Calculating the wavelet transforms takes a few minutes. Calculating the cross-correlations took another seven hours of computer time on this machine. After the preparations, it took approximately six seconds to find the nine most likely candidates for matching to a given photograph.

DISCUSSION AND CONCLUSION

User input is needed to distinguish the trailing edge from other edges in the photograph. Photographs of high quality and taken according to a strict protocol based on Arbom's 'measure of photoquality' (Arnbom, 1987) could generally be analysed without any correcting input from the analyst.

Due to the loss of information caused by the projection, the lack of independent confirmation of found similarities between contours, the possibility of contours changing over time and the existence of featureless trailing edges, it will be impossible to design a totally automated method to match different photographs of one individual.

Cross-correlating the wavelet transforms performed as measure of similarity is best in practice, but it seems to be quite possible that a better performing measure of similarity can be found.

Regrettably, no ordinal ordering was found, making it impossible to prove the absence of a matching photograph in the collection.

The set of nearest neighbours, presented in response to a given photograph, occasionally contained mutually matching photographs, although neither of these photographs matched the query image. Further analysis of this effect may be useful for the improvement of the algorithm.

Only a small set of photographs was in colour and this extra information was not used. However, experiments showed that the colour information is very useful in the extraction of the contour, and therefore the use of colour photographs is recommended.

Digital collections greatly facilitate the distribution of material and the possibilities of following individual sperm whales over longer periods and wider areas. The NAMSC has shown that the material can be shared while the copyright, and possible further details of the observation, remain with the contributor. The possibilities of setting up a world catalogue of sperm whale photographs deserve further study.

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Comparison of subjective and statistical methods of dive classification using data from a time-depth recorder attached to a gray whale (*Eschrichtius robustus*)

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ABSTRACT

This paper presents dive data obtained from the deployment of a suction-cup attached time-depth recorder (TDR) on a gray whale off the west coast of Vancouver Island, Canada. Data are presented in the form of dive profiles. This represents the first time that dive data have been collected from a gray whale. The data were used to compare subjective classification of dive types to statistical methods of classification, and to test the ability of the statistical methods to classify dives. Each dive was analysed using maximum depth, dive duration and bottom time variables for both subjective and statistical methods to make direct comparison of results. Subjective classification suggests that the tagged animal performed five distinct dive types. Two of these dive types, termed Interventilation and Feeding, were assigned a purpose. Two statistical techniques were then used to classify dives: *k*-means cluster analysis and discriminant function analysis. Cluster analysis and subjective classification showed poor agreement due to the statistical technique's inability to account for dive geometry. Discriminant function analysis proved more successful, although this technique also demonstrated some weakness in testing for dive geometry. It was concluded that while statistical analysis of dive data is useful to classify dive types in a general manner, subtle differences, which may be indicative of behavioural differences, still depend on subjective analysis for identification. Detailed analyses of the third, or depth, dimension of the marine mammal environment will be important for the development of effective management strategies, especially as whalewatching grows in popularity.

KEYWORDS: GRAY WHALE; DIVING; NORTH AMERICA; NORTHERN HEMISPHERE; PACIFIC OCEAN; RADIO-TAGGING

INTRODUCTION

Wildlife managers are currently faced with issues beyond the bounds of their historical practice. Non-consumptive wildlife use (e.g. wildlife viewing and photography) is a rapidly growing sector. Wildlife management is becoming more complicated due to both a large 'user' population and increasing economic impact (Duffus and Dearden, 1990; 1993). Detailed understanding of species' life history, ecology and behaviour (e.g. foraging, reproduction and spatial behaviour) will now, more than ever, dictate a programme's success in mitigating human impact on the focal species. Within the spectrum of wildlife watching activities, whale and dolphin watching has grown extremely rapidly (Hoyt, 1995; 2000). Management concerns have now arisen in many locations and for several species (IFAW Tethys and Europe Conservation, 1995; IFAW, 1998). The issue is also being examined by the International Whaling Commission (e.g. IWC, 1997a) and its Scientific Committee (e.g. IWC, 1997b; 1999; 2000).

Records of underwater behaviour are now available through the use of time-depth recorders (TDRs). This paper reports on the use of a TDR attached to a gray whale (*Eschrichtius robustus*). Individual dives ($n = 651$) were analysed using data collected from Clayoquot Sound, on the west coast of Vancouver Island, Canada. Gray whales aggregate and forage in Clayoquot Sound between May and September and a whalewatching industry has developed in the villages of Tofino and Ucluelet based on whales (approximately 100) that move between Barkley, Clayoquot and Nootka Sounds during these months (Duffus, 1996). While information from a single individual does not provide a foundation upon which to generalise behaviour, it does provide the first record of the underwater behaviour of a gray whale. More importantly, these data provide an opportunity to compare and analyse dive classification methods in a dataset for which feeding dives (the main behaviour of gray whales in Clayoquot Sound during the summer) are identifiable due to their foraging habits.

In the past, analyses of dive data collected by TDRs initially focused on maximum depth and duration of dives (e.g. Le Boeuf *et al.*, 1988; 1989; DeLong and Stewart, 1991). Subsequently, researchers expanded their analyses to include shape (depth *versus* time) to classify dive types (e.g. Le Boeuf *et al.*, 1992; 1993; Martin *et al.*, 1993; 1994; Baird, 1995). This type of analysis typically relies on subjective examination of individual dive records to differentiate shape.

Analysis of dive data beyond summary description is still in its infancy. The use of multivariate statistical techniques has been introduced to deal with large datasets and to reduce bias in subjective analysis (Hindell *et al.*, 1991; Schreer and Testa, 1995; 1996; Burns *et al.*, 1997). However, subtle differences in shape, discernible in subjective analysis, may not be recognised statistically (Schreer and Testa, 1996). The desire to derive more than description, however, will continue to stimulate advances in this area.

METHODS

The tag

The tag used was based on the original design of Goodyear (1981; 1989). The attachment mechanism follows the design of Goodyear, modified by Baird (1995). A VHF transmitter (*Telonics* Dart 4, Mesa, AZ) and time-depth recorder (Mk5 TDR, Wildlife Computers, Redmond, WA) were incorporated into the tag body. The depth sensor (precision +/- 1m) on the TDR was set to record once per second for this study. Data collected during deployment was stored and downloaded following recovery of the tag.

The attachment mechanism consisted of a 7.8cm, soft rubber suction cup, fastened to the tag body by flexible plastic tubing. The detachment mechanism was a stainless steel tube running through the stalk of the suction cup opening into the inside of the suction area. A stainless steel spring maintained a stainless steel washer in constant contact with a magnesium cap screwed onto the top of the tube. The detachment mechanism relied on electrolysis to erode the cap, releasing the device. Once free, the tag was located using a VHF receiver and 3-element Yagi antenna.

The TDR tag was attached to a gray whale foraging with a group of 12 animals at Rafael Point, Flores Island, on 6 August 1994. A SCUBA diver reconnaissance and plankton tows, undertaken from a support vessel during the tagging period, revealed that the animal was feeding on planktonic crab larvae (*Pachycheles* spp. and *Petrolisthes* spp.) swarming 0-3m above the ocean bottom at an average depth of 18m. The tag remained attached for 8 hours, 21 minutes, collecting 29,842 depth points, representing 651 dives.

Data were downloaded from the TDR in a hexadecimal format for analysis with DIVE ANALYSIS (Wildlife Computers, Redmond, WA) and a decimal-formatted listing of each single-depth reading for statistical analysis. DIVE ANALYSIS produced individual, two-dimensional dive profiles, displayed in order of occurrence. DIVE ANALYSIS also generated the following user-selected variables for each dive: dive duration, maximum depth, bottom time, descent time, average descent rate, ascent time and average ascent rate.

Classification techniques

Dives were classified subjectively based on shape, dive duration, maximum depth and bottom time variables generated for each dive. Fig. 1 illustrates the decision tree employed in the subjective classification process. Dives were sorted into classes through *k*-means cluster analysis based on *k a priori* user-designated clusters (Everitt, 1980). This method allows direct comparison with the subjective classification.

The first *k*-means clusters were generated using the same variables as the subjective classification (dive duration, maximum depth and bottom time). To compare the results of the two methods, dives classified subjectively were grouped according to the clusters generated statistically.

A second cluster analysis was performed using converted variables. Maximum depths were converted to z-scores to reduce the effect of the large range of the variable relative to the other two variables. Relative bottom time was calculated by dividing bottom time by maximum depth to differentiate between dives to similar depths with varying bottom times (e.g. v-shaped dives *versus* square-shaped dives). The dive duration variable was not altered. Results using the dive duration, maximum depth z-score and relative bottom time variables were then compared with the subjective classification.

Discriminant Function Analysis (DFA) predicts group membership by creating a linear regression function based on the test variables. This function is the least squares predictor of group membership, whereby observations are split into two groups by the discriminant function (Sokal and Rohlf, 1981). In cases where observations belong to more than two groups, multiple discriminant functions are created. The number of functions created is either equal to the number of variables or one less than the number of groups, whichever is lower. The first discriminant function maximises the between-groups to within-groups sum of squares, the second function derived is the second best explainer of variance, and so on (Norusis, 1994). For the data in this study, three discriminant functions were derived, equalling the number of variables.

By converting the subjectively determined dive classes into numerals (e.g. Feeding = 5) and inserting them as a variable (along with dive duration, maximum depth and bottom time) into the analysis, the accuracy of the subjective classifications is tested by comparing the analysis results to the subjective classification (*sensu* Schreer and Testa, 1996). The resulting comparison calculates an error rate of the subjectively determined classifications.

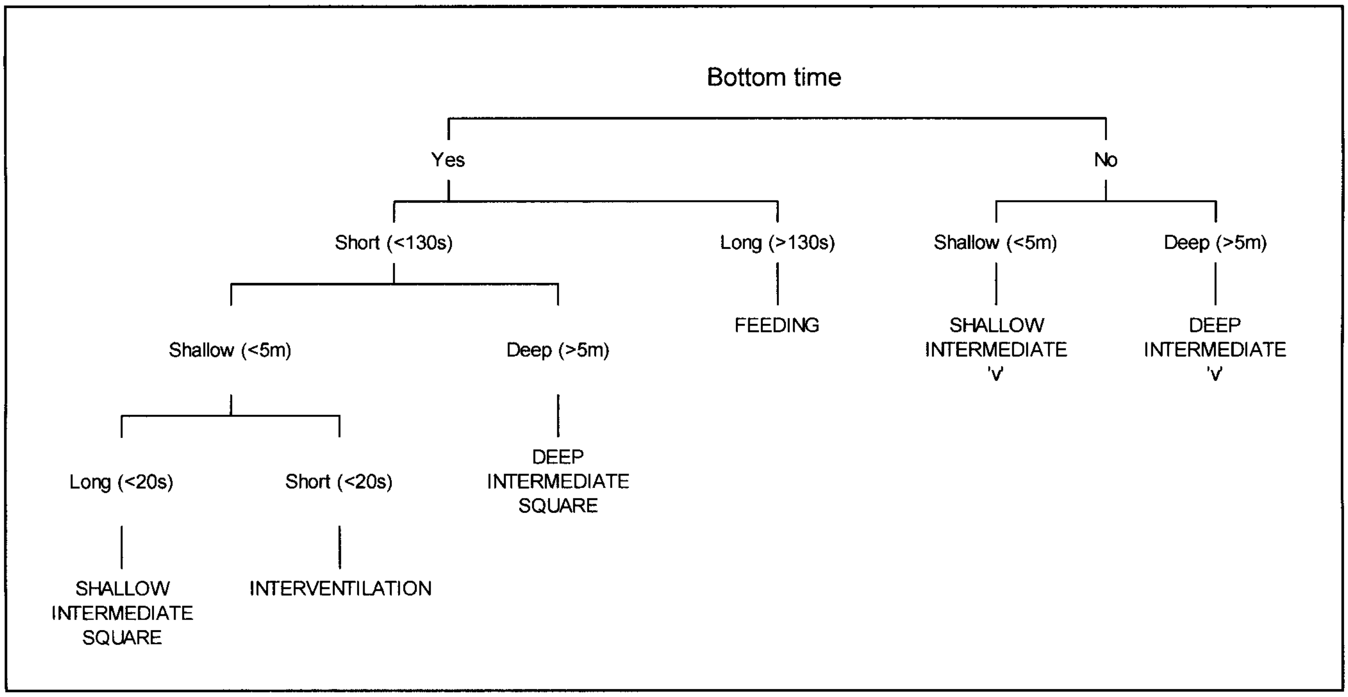

Fig. 1. Decision tree for subjective classification of dive types.

RESULTS

Subjective analysis classes were labelled: (1) Interventilation; (2) Shallow Intermediate Square; (3) Deep Intermediate 'v'; (4) Deep Intermediate Square; and (5) Feeding (Fig. 2). Function was ascribed to the Interventilation and Feeding dive types. Interventilation refers to short, shallow dives performed during oxygen recharge and Feeding refers to long, deep dives to the prey patch. There is no basis presently upon which to ascribe function to the other three dive types.

K-means cluster analysis is based on five groups, replicating the number of groups categorised in the subjective method in order to compare the two classification methods. The summary statistics as well as the location of proportions of members in other categories classified by each technique respectively illustrates the level of agreement in the two techniques (Table 1).

Clustering of geometrically distinct dives within the same groups and the large range of the maximum depth variable was addressed in a second cluster analysis. Two new variables were used for this analysis: maximum depth converted to a z-score and relative bottom time calculated by dividing bottom time by maximum depth. The second cluster analysis classification was again based on five clusters. The new clusters again agree poorly with the subjective classification (Table 2).

DFA was used to test the validity of the subjective classifications by predicting group membership (Table 3). There was better agreement between the discriminant functions and the subjective classifications than with the *k*-means cluster analyses and subjective classification. The only subjective category that DFA determined to be misclassified was the Shallow Intermediate Square dive type, which had only 21.6% agreement. The overall error rate, given by the number of dives identified as misclassified divided by the total number of dives, was 8.6%.

DISCUSSION

In the subjective examination of the data, the TDR provided evidence of five different types of dive. Function was ascribed to two of these. The short, shallow, Interventilation dives were part of the cycle of oxygen recharge that the whales perform between pursuit dives to obtain prey. The Feeding dives appeared readily discernible by their length, depth and shape, and showed the animal pursuing supra-benthic swarms, confirmed by underwater observation. The three intermediate dives, while classified through the subjective process as separate dive types, were too scarce in this dataset to attempt any explanation. Nothing in the dive sequence or geographic location provided clues as to their function.

Dives classified by both subjective and statistical methods explore the application of multivariate statistical techniques to dive data. The small dataset ($n = 651$) allowed inspection of every dive to compare subjective and statistical analysis of gray whale diving data for the first time. By using the same variables for both the subjective and initial *k*-means cluster analysis (maximum depth, dive duration, bottom time) a direct route for comparison between the two methods is possible. The subjective method focuses primarily on geometry as well as the maximum depth, dive duration and bottom time, with the ultimate goal of assigning purpose to each dive. However, assigning purpose, with *a priori* ideas (e.g. feeding, oxygen recharge), may create bias. Statistical analysis applies rigid criteria to data to provide comparison.

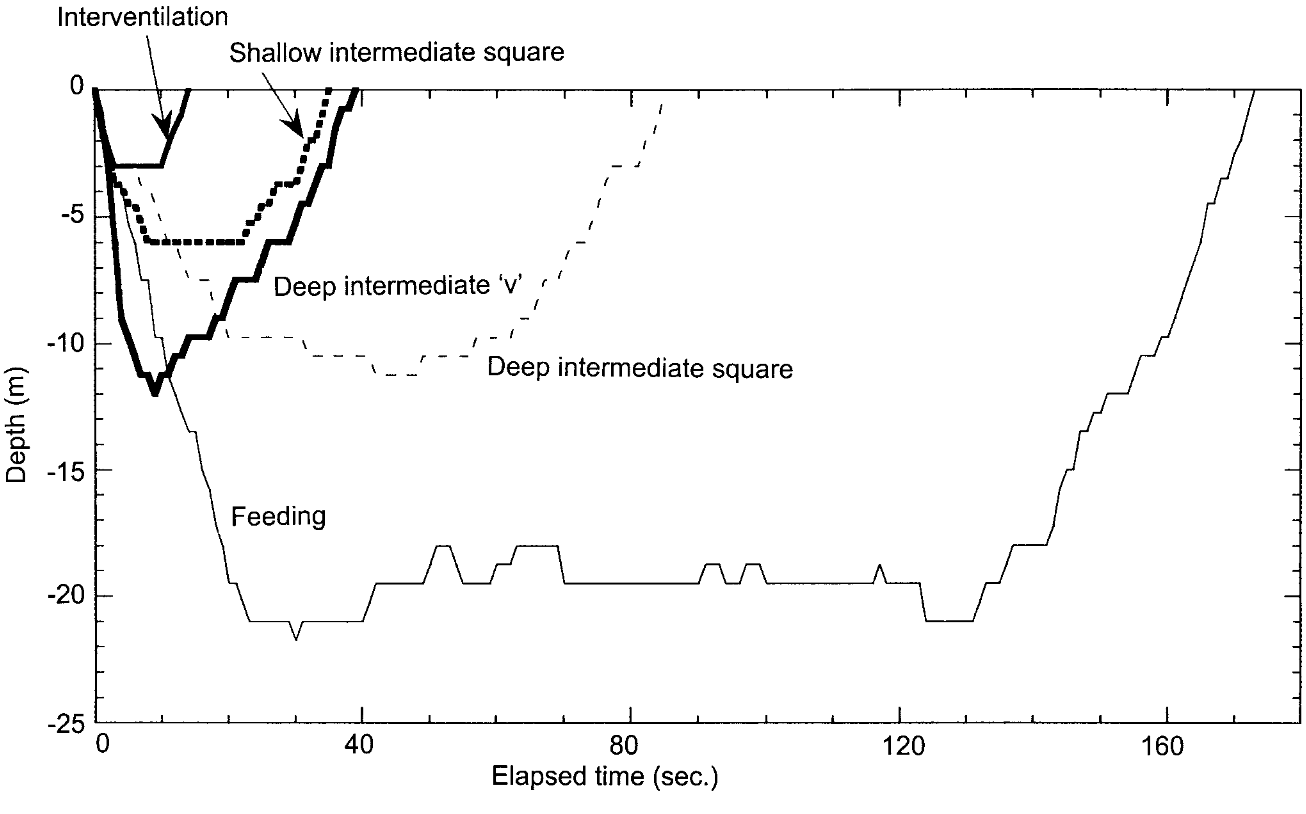

Fig. 2. Subjectively classified dive profile examples.

Table 1
Comparison of cluster analysis to subjective classification.
Key: Depth = Mean Maximum Depth; Dive = Mean Dive Duration; Bottom = Mean Bottom Time. Under 'Cluster analysis' and 'Subjective' I = Interventilation; SIS = Shallow Intermediate Square; DIV = Deep Intermediate 'V'; DIS = Deep Intermediate Square; F = Feeding. Under 'Subjective' Cluster 1 = 1; Cluster 2 = 2; Cluster 3 = 3; Cluster 4 = 4; Cluster 5 = 5.

	Cluster analysis	Subjective
	Cluster 1 (*n*=515)	**I (*n*=466)**
Depth (m)	2.2	2.2
Dive (s)	13.3	12.6
Bottom (s)	7.3	0.12
Classification:	90.5% in I; 9.5% in SIS	100% in 1
	Cluster 2 (*n*=40)	**SIS (*n*=51)**
Depth (m)	6.8	3.5
Dive (s)	56.3	28.2
Bottom (s)	31.4	9.8
Classification:	5.0% in SIS; 32.5% in DIV; 62.5% in DIV	96.1% in 1; 3.9% in 2
	Cluster 3 (*n*=17)	**DIV (*n*=18)**
Depth (m)	12.0	9.0
Dive (s)	110.3	44.4
Bottom (s)	53.3	11.0
Classification:	17.6% in DIV; 47.1% in DIS; 35.3% in F	72.2% in 2; 16.7% in 3; 11.1% in 4
	Cluster 4 (*n*=42)	**DIS (*n*=33)**
Depth (m)	16.8	8.0
Dive (s)	178.8	79.8
Bottom (s)	125.4	46.2
Classification:	4.8% in DIV; 95.2% in F	75.8% in 2; 24.2% in 3
	Cluster 5 (*n*=37)	**F (*n*=83)**
Depth (m)	18.8	17.5
Dive (s)	208.2	190.8
Bottom (s)	150.6	130.4
	100% in F	48.2% in 4; 44.6% in 5; 7.7% in 3

Table 2
Comparison of second cluster analysis using transformed variables to subjective classification. Under 'Cluster analysis' and 'Subjective' I = Interventilation; SIS = Shallow Intermediate Square; DIV = Deep Intermediate 'V'; DIS = Deep Intermediate Square; F = Feeding. Under 'Subjective' Cluster 1 = 1; Cluster 2 = 2; Cluster 3 = 3; Cluster 4 = 4; Cluster 5 = 5.

Cluster analysis	Subjective
Cluster 1 (*n*=504)	**I (*n*=466)**
92.3% in I; 7.7% in SIS	99.7% in 1; 0.03% in 2
Cluster 2 (*n*=54)	**SIS (*n*=51)**
1.9% in I; 22.2% in SIS; 27.8% in DIV; 48.1% in DIS	76.5% in 1; 23.5% in 2
Cluster 3 (*n*=20)	**DIV (*n*=18)**
15% in DIV; 35% in DIS; 50% in F	83.3% in 2; 16.7% in 3
Cluster 4 (*n*=37)	**DIS (*n*=33)**
100% in F	78.8% in 2; 21.2% in 3
Cluster 5 (*n*=36)	**F (*n*=83)**
100% in F	44.6% in 4; 43.4% in 5; 12.0% in 3

Table 3
Predicted group membership determined by discriminant function. Under 'Subjective' I = Interventilation; SIS = Shallow Intermediate Square; DIV = Deep Intermediate 'V'; DIS = Deep Intermediate Square; F = Feeding.

	% DFA predicted group membership (*n*)				
Subjective group	1	2	3	4	5
I (*n*=466)	99.6	0.4	0	0	0
SIS (*n*=51)	78.4	21.6	0	0	0
DIV (*n*=18)	0	0	66.7	22.2	11.1
DIS (*n*=33)	0	0	9.1	87.9	3.0
F (*n*=83)	0	0	1.2	3.6	95.2

While it is possible that dive types may be continuous, and not amenable to separation by artificial boundaries in some circumstances, in this case the advice of Shreer and Testa (1995) was followed, i.e. that cluster analysis is the most efficient multivariate procedure for analysing dive data solely by statistical techniques.

The difficulty in the statistical analysis lies in its insensitivity to shape. The initial cluster analysis (Table 1) has no variable that deals with depth and geometry simultaneously. The Deep Intermediate dives, both 'v' and square, are scattered into three central clusters with depth centres of 6.8m, 12m and 16.8m. The subjective analysis separates the two Deep Intermediate classes not by depth, with 9.0m and 8.0m means, but by bottom time, 10.8s and 46.2s, respectively, which clearly differentiates between the distinct dive shapes.

The division of Feeding dives between three clusters is due to the range of the maximum depth variable for Feeding dives (8.33m), resulting in longer dive time and bottom time centres for the deeper dive clusters. The range may be explained by two aspects of the environment: (1) although the prey was observed by SCUBA divers to be supra-benthic during the tagging session, prey swarms may have been several meters thick in some areas; and (2) the rocky substrate results in variable depths throughout the Rafael Point feeding site. Identifiable geometric characteristics of feeding dives (long, deep dives with long, flat bottom times) and knowledge of environmental conditions, included in subjective analysis, could not be considered in cluster analysis.

Depth may also be the main criterion for clustering 96.1% of Shallow Intermediate Square dives in the same cluster as Interventilation dives. However, the subjective analysis revealed the Shallow Intermediate Square dive to be more than twice the duration of the Interventilation dive.

The second cluster analysis attempts to moderate the large range of the depth variable and address the relationship of bottom time to depth. However, dive geometry shape remains undistinguished. The percentages of Deep Intermediate 'v' and Deep Intermediate Square dives grouped together in Cluster 2 (83.3% and 78.8% respectively) is even higher with the new variables.

The insensitivity to shape in both *k*-means cluster analyses reinforces the importance of subjective analysis. The ability to subjectively analyse and allocate dives to particular groups appears essential for analysis of dive behaviour to assign purpose to dives. This level of understanding is needed for effective management. However, databases containing thousands of dive records may prohibit the possibility of individual subjective analysis. Random selection of < 1,000 dives from a database for subjective analysis may be useful, although the chance of missing a rare, yet potentially important, diving behaviour is a possibility. Although Burns *et al.* (1997) describe a method for transforming dive data that cluster analysis can classify into general groups, their method was not used at this stage of the analysis for three reasons: (1) Burns *et al.* were analysing Weddell seal dive data which had much longer average dive durations ($\bar{x} = 8.83 \pm 1.49$min) compared to the large percentage of short dives ($\bar{x} = 0.67 \pm 1.03$ min for all dives) in our own dataset - their method would not have given us a fine enough scale to work with; (2) Burns *et al.* had to subsequently divide groups by depth, whereas for our data, with an identifiable food source depth, depth had to be a primary factor in classification; and (3) as our primary goal was to compare subjective with statistical classification the same variables were needed for both methods. However, the method described by Burns *et al.* is useful for the analysis of lengthy dives and is not ruled out for use in the future, especially with larger datasets.

The inability to account for shape encountered in this study poses a problem, as shape must be taken into account in assigning purpose. In the case of some skim-feeding baleen whales (or benthic feeding gray whales), in which a long, flat bottom time indicates a feeding behaviour, this problem is not as severe. In other situations, however, this may not be the case.

DFA can be used as a statistical test of the grouping algorithms created by other methods (Schreer and Testa, 1995). In this study, it was used to test the subjective classifications. As in the cluster analysis, DFA determined Interventilation and Shallow Intermediate Square dives to be similar. DFA determined that 78.4% of Shallow Intermediate Square dives belonged in the same group as Interventilation dives (Table 3).

This result leaves a small group of 13 dives (including two from the Interventilation dive class) as the DFA analogue of the Shallow Intermediate Square dive class. Although both cluster analysis and DFA revealed that these two dive types were similar statistically, it remains difficult to conclude whether these two dive types should be considered as one. The mean dive durations of the two dive types, when classed subjectively, were 12.6 and 28.2 seconds, respectively, suggesting a difference. This difference could have an energetic component. With only one animal's dive behaviours recorded and only 51 dives in the Shallow Intermediate Square dive class, there are insufficient data for a more robust interpretation.

With respect to the other subjectively determined dive types, DFA results agree more than cluster analysis. The Feeding dive type was determined by DFA to be 95.2% correct. DFA also appeared more adept at analysing shape. Deep Intermediate 'v' and Deep Intermediate Square dive types were determined by DFA to be classified 66.7% and 87.9% correctly, and still represented the highest variability across different classes.

The overall error rate (number of misclassified dives divided by total number of dives) for the DFA analysis was 8.6%. This percentage may be artificially low due to the high percentage of agreement between the subjective and DFA classifications for the Interventilation dives, which constituted 71.5% of the sample. Schreer and Testa (1996) reported a mean error rate of 48%, calculated from a number of individual DFA analyses using different datasets for their Weddell seal study, a much higher rate than this study. Schreer and Testa, however, employed a much larger dataset and subjectively identified nine dive types, several classes of which are only subtly different. It is also possible that the gray whale tagged in this study performed dives that were drastically different (based on the maximum depth, dive duration and bottom time variables used) and thus easily identified subjectively.

CONCLUSION

This study presents the first application of a TDR tag on a gray whale. While the single application does not provide an appropriate dataset upon which to base generalised behavioural hypotheses, it does provide an opportunity to examine the applicability of statistical methods to classify dives from a continuous dive record.

Continued work with subjective and multivariate analysis techniques for dive data will prove important for the conservation and management of marine mammals, especially in light of the growing whalewatching industry throughout the world. Surface behaviour data has yet to yield much significant change in the presence of vessel traffic. Neither technique on its own is completely satisfactory in dealing with the differences in dive morphology. Exploratory application of multivariate analyses methods, such as those by Schreer and Testa (1995; 1996), Burns *et al.* (1997), and those emerging from this study, reveal the statistical techniques' ability, at least in part, to identify characteristic dive types. However, subjective analysis, examining overall shape of each dive, remains an important element of analysis. The effectiveness of the statistical techniques employed in this study to test for shape, within similar dive depths and durations, was not sufficient; however, a solely subjective analysis may introduce bias. A combination of sub-sampled subjective runs and large scale statistical testing may prove the most effective route for large datasets, coupled with sound biological knowledge of the animal and its behaviours.

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Bottlenose dolphins (*Tursiops truncatus*) increase whistling in the presence of 'swim-with-dolphin' tour operations

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ABSTRACT

The impact of cetacean eco-tourism on subject animals is not clearly understood. Studies that monitor this impact have traditionally concentrated on observable surface behaviour despite the fact that sound is the primary communication channel for cetaceans. This study monitored whistle production in free ranging bottlenose dolphins (*Tursiops truncatus*) to evaluate if dolphins vocalise at different rates in response to commercial dolphin-swim boats. Thirty-two hours of sound were recorded in the austral spring and summer of 1995/96. Results indicate that whistle production is significantly greater in the presence of commercial dolphin swim boats, regardless of dolphins' behavioural state prior to the arrival of the vessels. The increase in whistle production suggests that group cohesion may be affected during approaches made by commercial dolphin swim tour-operators or may serve some other social function. Monitoring vocal behaviour offers another insight into short-term human impacts on cetaceans.

KEYWORDS: BOTTLENOSE DOLPHIN; ACOUSTICS; VOCALISATION; BEHAVIOUR; WHALEWATCHING

INTRODUCTION

Bottlenose dolphins (*Tursiops truncatus*) have a long history of interaction with humans (e.g. Lockyer, 1990). Commercial 'swim-with-dolphin' and 'dolphin-watching' tour operators are now adding to the number of boats encountered by dolphins. Resident populations of dolphins are more susceptible to developing chronic effects from commercial cetacean watching operations than, for example non-resident migratory baleen whales, primarily because the same resident individuals may be targeted each day (Corkeron, 1996). Dolphin watching operations have been shown to alter dolphins' behaviour, apparently due to the operators' tendency to follow and stay with dolphins (Acevedo, 1991; Janik and Thompson, 1996). The effect of this form of tourism industry on resident dolphin populations is still not clearly understood. Port Phillip Bay, Victoria has a resident population of inshore bottlenose dolphins that are exposed to recreational users, five commercial 'dolphin-swim' tour operators and three 'dolphin-watching' boats (Scarpaci *et al.*, 2000). The length of the trips ranges from 3.5-4.5 hours with each boat departing 2-3 times a day. Although sound is the primary dolphin communication channel (Caldwell *et al.*, 1990; Smolker *et al.*, 1993), and is also used for echolocation (Janik *et al.*, 1994), studies on the anthropogenic impacts on dolphins have tended to concentrate on observable surface behaviour. This study assesses how dolphins' sound production changed depending on the presence or absence of dolphin-swim tour operators.

MATERIAL AND METHODS

The study was conducted at Port Phillip Bay (38°05'S, 144°50'E), on the southeastern coast of Victoria, Australia (Fig. 1). The study site was on the southernmost end of the bay and covered an area of 26.25km^2. This area was selected because it is the most intensively used by the commercial dolphin-swim charters. All commercial dolphin-swim boats depart from Sorrento Pier with the exception of one boat, which departs from Queenscliff. Dolphin watching boats depart from both Sorrento and Queenscliff primarily because these boats may also operate as ferries between these locations.

Dolphins were observed in the Bay from September 1995 to February 1996. Recordings and observations were conducted from a 4.7m aluminium dinghy equipped with an 8hp outboard motor. A group of dolphins was defined as an aggregation of individuals swimming in a coordinated manner within 100m of each other while displaying the same type of behaviour (Shane, 1990). Data were collected from focal groups rather than from focal individuals because it was not possible to identify individual dolphins or determine which individual dolphin was vocalising. Sound recordings were conducted simultaneously with behavioural observations. The dolphins were observed using: (1) continuous sampling for whistle production; and (2) five minute scan samples of their behavioural state and group size as described by Altmann (1974). This information was immediately transcribed onto prepared data sheets. The recordings were later analysed by ear and compared against data sheets to ensure accuracy; any that did not tally were rejected.

To minimise the effect of the presence of our research boat, the following precautions were taken: (i) no data were collected for the first 10 minutes after encountering a group of dolphins; and (ii) dolphins were approached according to the 1990 Wildlife Whale Watching Regulations[1]. A total of 32 hours of sound recordings was made from September to February 1995. 'Absence' refers to no boats in the area with the exception of the research boat (with its engine off) and 'presence' refers to the presence of at least one dolphin-swim tour operator. Observations began in the early morning before the commercial dolphin-swim operators left the dock. This allowed the researcher to monitor sound production

[1] Wildlife Whale Watching Regulations 1990. SR 102. VGPO, Melbourne, Australia.

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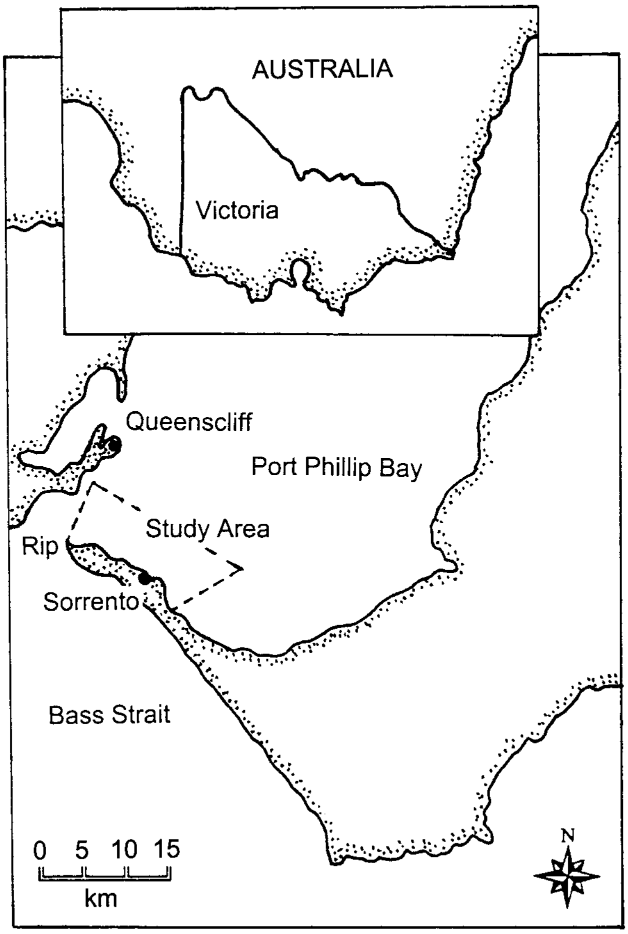

Fig. 1. Map of Port Phillip Bay, Victoria, Australia. Box caption indicates the southern end of Port Phillip Bay and the study area.

prior to dolphins being exposed to commercial dolphin-swim boats on the day of observations. Observations were made for 30-120min before any commercial dolphin-swim operators approached, followed by additional 30-135min of observation in the presence of dolphin-swim operators. Vocalisations were recorded underwater using a custom built mono-hydrophone and pre-amplifier. A standard audio tape recorder (*National* RX-C37) was used. The frequency response of the equipment was 20Hz to 16kHz, limited by the tape recorder. Most sounds produced by the dolphins were categorised by ear as: whistles; echolocation; or 'burst pulsed sounds' as defined by Caldwell *et al.* (1990) and Buck and Tyack (1993). Whistles were defined as continuous narrow band sound emission delineated by breaks (Schultz and Corkeron, 1994) and are the only vocalisation type analysed in this paper.

At distances exceeding 200m, the hydrophone was unable to record whistles by a vocalising group clearly. Once the research vessel moved within 200m of the dolphins, whistles could be heard clearly. All sound recordings occurred within 200m of the most distant animal in the group which ensured that the proportion of whistles detected remained the same in all situations (presence and absence of commercial dolphin-swim operators). If the dolphins moved outside the 200m range, the hydrophone was collected from the water and the boat re-approached within 200m of the focal group. During this time, no data on whistle production could be recorded. If more than one group of dolphins was observed within 200m of the boat, data were disregarded. This ensured that the whistles heard were from the focal group. On the arrival of a commercial dolphin-swim boat, sound production was recorded in the presence of dolphin-swim boats. In most instances swimmers were placed into the water after the operator approached the dolphins. If recreational boats (non-commercial marine vessels including jet skis) were observed during sampling, these data were disregarded from the sample. The results of this study do not include sound production after the departure of an operator because in many cases, once a group of dolphins was sighted the operators would work cooperatively with one following the other until dusk or the presence of operators would attract recreational boats to the area.

Behaviour

Behavioural states were defined as travel, feeding or social, following Shane (1990). Units of behaviour associated with each state were derived from Corkeron (1995).

Travel behaviour was defined as steady movement of a group of dolphins in one direction. During *feeding behaviour* dolphins engaged in either long dives (preceded by fluke up or fluke down dives, or peduncle arches) or erratic swimming, and were often seen chasing fish at the surface of the water. Feeding dolphins' dives were temporally, but not necessarily spatially, coordinated.

During *social behaviour*, animals were involved in active surface behaviour that included interactions with other group members. Units of behaviour observed during socialising included aerial leaps, rubbing, biting and splashing.

Rate of whistle production

The rate of whistle production by bottlenose dolphins was standardised by observation time and group size. For this, the total number of whistles produced during an observed behavioural activity was divided by the time spent observing that group of bottlenose dolphins in that behavioural state for each sighting, divided by the number of dolphins present. This result (whistle/min/dolphin) was calculated for each behaviour in every experiment for each period in the presence of 'dolphin-swim' tour operators and in the absence of 'dolphin-swim' tour operators. The individual data points were used in statistical analysis to calculate the median.

Bottlenose dolphins were the only cetacean species present during all recordings. The number of whistles in each time period was scored. Qualitative features of whistles, such as frequency and contour, were not measured. Data were analysed using SPSS (8.0) and MiniTab (11.2) on a PC.

Statistical analysis

As data were not normally distributed, non-parametric tests (Zar, 1984) were used. The Kruskall-Wallis test (Zar, 1984) was used to determine the effect of whistle rate in the presence and absence of dolphin-swim operators. The Mann-Whitney U test (Zar, 1984) determined if whistle rate differed in the presence and absence of commercial dolphin swim-boats for each category of behaviour.

RESULTS

The rate at which dolphins whistled (whistles/min) differed depending on the presence of commercial swim-with-dolphin operators ($\chi^2 = 47.64$, df = 5, $p = 0.001$, $n = 98$); see Fig. 2. Data were further analysed according to behavioural state and vessel presence. During travel ($p = 0.001$), feeding ($p = 0.001$) and socialising ($p = 0.001$), dolphins produced more whistles when dolphin-swim tour operators were present than when they were not.

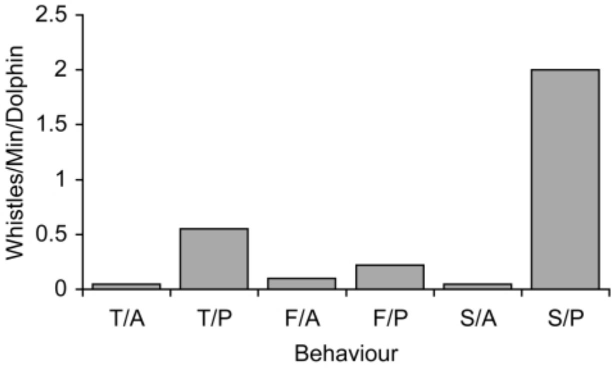

Fig. 2. The median number of whistles produced per minute per dolphin in the presence (P) and absence (A) of commercial dolphin-swim tour operators during travel (T), feeding (F) and social (S) behaviour.

DISCUSSION

Bottlenose dolphins living in inshore coastal waters are frequently in contact with humans (e.g. Acevedo, 1991). The cetacean viewing industry has introduced a new source of possible impact on resident populations of inshore dolphins, however the extent to which this affects dolphin behaviour remains uninvestigated in most cases. This paper shows an increase in whistle production during travel, feeding and social behaviour in the presence of dolphin-swim operators for bottlenose dolphins in Port Phillip Bay, Victoria. It is believed that the function of the whistles is to allow individual recognition of members in a social group (Caldwell and Caldwell, 1965; Caldwell *et al.*, 1990) and as a contact call to maintain physical and vocal contact (Smolker *et al.*, 1993; Janik and Slater, 1998; Smolker and Pepper, 1999). The observed increase in whistle production suggests that group cohesion is somehow affected during approaches made by commercial dolphin swim tour operators. Either the approaches made by tour operators result in the physical separation of individuals in the group, or the increase in ambient noise created by a vessel's presence leaves dolphins needing to ascertain the whereabouts of other group members. Alternatively, an increase in whistling could also mean dolphins are more excited around commercial dolphin-swim boats. An increase in whistling rates has been documented during excitement and stress in Hawaiian spinner dolphins, *Stenella longirostris* (Norris *et al.*, 1994) and during bow riding in bottlenose dolphins (Wells *et al.*, 1980). This study uses a novel technique to monitor the impacts of cetacean eco-tourism. The results suggest an immediate acoustic response by wild dolphins as a result of the presence of dolphin-swim tour boats. The authors suggest that monitoring acoustic responses is fundamental to our understanding of the impacts of eco-tourism on cetacean populations.

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Results of passive acoustic surveys for odontocetes in the Southern Ocean

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ABSTRACT

Passive acoustic surveys for cetaceans were carried out from the British Antarctic Survey research vessel *James Clark Ross* in the region of South Georgia in the austral summer of 1998/99 and also during the IWC/CCAMLR collaborative survey in January/February 2000. The acoustic surveys were conducted concurrently with visual observations. A simple two element hydrophone array, sensitive to frequencies of between 300Hz and 24kHz, was towed on a 400m cable astern of the vessel. The total combined acoustic effort for the two surveys was 569 hours along 11,491km (6,205 n.miles) of trackline. On both surveys, stereo recordings were made for 30 seconds every two minutes. Acoustic detections were made of sperm, killer, pilot and southern bottlenose whales and hourglass dolphins. Reliable density estimates were only possible for sperm whales but the data on other species provide useful indications of relative distribution. A total of 42 individual sperm whales were detected and of these 33 were located by crossing bearings derived acoustically from several points along the trackline. Analysis of perpendicular distances pooled across both surveys gave an estimated strip half width of 8.0km (95% CI 6.4-9.9km) giving an overall density estimate for sperm whales of 0.13 and 0.19 whales per 1,000km^2 from the 1998/99 and 2000 surveys, respectively. The methods supported estimates of sperm whale density using standard line-transect analyses based on perpendicular distances. The need to filter sounds below 300Hz to reduce ship noise largely precluded monitoring for mysticete vocalisations.

KEYWORDS: SPERM WHALE; ACOUSTICS; SURVEY-COMBINED; SOWER 2000; SOUTHERN OCEAN SANCTUARY

INTRODUCTION

Passive acoustic detection systems have been successfully used on a number of cetacean surveys from large oceanographic research vessels during multi-disciplinary cruises in the Southern Ocean (Gillespie, 1997; Pierpoint *et al.*, 1997; Leaper and Scheidat, 1998; Rendell *et al.*, 1998). Acoustic monitoring provides an opportunity to collect data in conditions unsuitable for visual observations such as darkness, poor visibility and high sea states. The use of simple towed hydrophones to monitor cetacean vocalisations enables quantifiable data to be collected at minimal cost, without requiring dedicated ship time. The equipment can be maintained by one or two researchers who can also perform other research tasks. The scope of previous surveys has often been restricted by the onerous and somewhat subjective task of listening to many hours of recordings. Recent increases in the processor speed of readily available computers and development of appropriate software now allows detections to be made automatically in real time. This alleviates the need to make and listen to recordings and also introduces a greater level of objectivity into the survey process. The software used in this study was designed to detect and measure bearings to click type vocalisations from odontocetes. It is especially suitable for sperm whales (*Physeter macrocephalus*) which are known to make loud, regular clicks for the majority of the time that they are underwater (Goold and Jones, 1995).

The British Antarctic Survey (BAS) has conducted research in the Scotia Sea for a number of years, and particularly in the area around South Georgia, with annual research cruises between 1995 and 2000. Particular attention has been placed on examining the determinants of the at-sea distribution of marine predators (e.g. Reid *et al.*, 2000). This paper describes two passive acoustic surveys from the UK research vessel *James Clark Ross*. The first survey was conducted in December/January 1998/99 as part of the BAS ‘Core Programme’ and the second in January/February 2000 as part of a collaboration between the International Whaling Commission (IWC) and the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR). A key aim of both surveys was to contribute to the objectives of the IWC SOWER 2000 programme, namely to ‘define how spatial and temporal variability in the physical and biological environment influence cetacean species’ (IWC, 2000). The 2000 survey was conducted during a synoptic krill survey in CCAMLR Area 48. Both surveys were conducted concurrently with visual observations and during the IWC/CCAMLR survey a team of IWC observers conducted a sightings survey using Buckland-Turnock type methodology (Buckland and Turnock, 1992) with independent observers using 25x magnification ‘big eye’ and 7x binoculars. Three vessels were involved in the IWC/CCAMLR visual survey but only one set of acoustic equipment, deployed from the *James Clark Ross*, was used.

The transects for each survey were designed according to the primary objectives of each cruise. In the 1998/99 BAS survey the large-scale oceanographic transect across the Maurice Ewing Bank was designed to cross the Polar Frontal region approximately perpendicular to the axis of the front. This transect provided data on large-scale oceanographic features with detailed biological sampling at 22 stations, 35km apart. The ‘Core Box’ transects were designed to provide mesoscale surveys to obtain finer scale information on the distribution and abundance of krill (*Euphasia superba*) and other key organisms close to South Georgia. The two ‘Core Boxes’ were approximately 80 × 100km and these were each surveyed by five pairs of transects approximately perpendicular to the shelf break (Fig. 1). The 2000 IWC/CCAMLR survey was based on transects designed for the estimation of krill biomass using active

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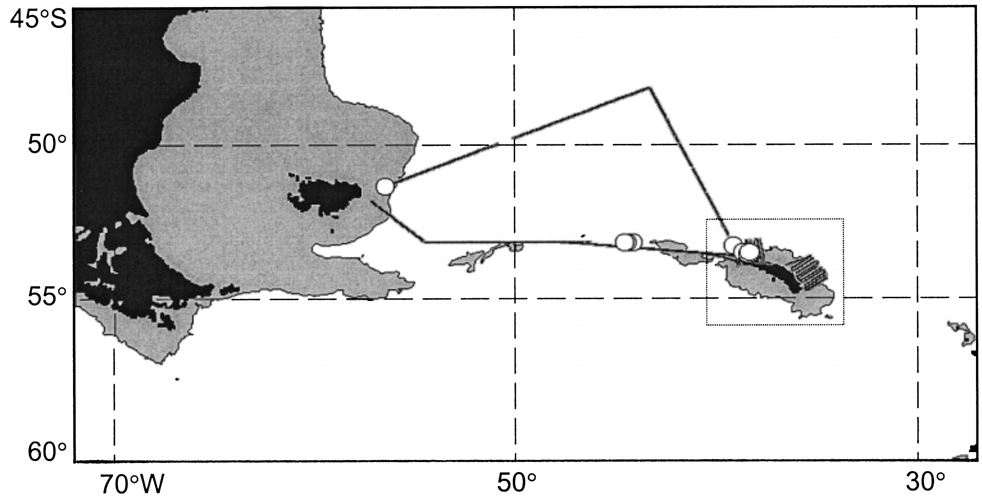

Fig. 1. Acoustic survey track and locations of sperm whale detections (open circles) during December-January 1998/99 BAS survey. The two 'Core Boxes' around South Georgia are shown in more detail in Fig. 4. Grey shaded area indicates water depths of less than 1,000m.

acoustic methods (Fig. 2). The randomised parallel transects were chosen so that it would be possible to use classical design-based statistical analysis methods as well as techniques such as spatial modelling (e.g. Hedley *et al.*, 1999). Transects were conducted between local dawn and dusk with sampling stations during the hours of darkness.

The main limiting factor to detecting whales acoustically from a moving vessel is the noise from the vessel. The *James Clark Ross* is particularly suitable for this kind of work because the ship was designed to be as quiet as possible. Nevertheless, the vessel was still the dominant source of low frequency noise and high pass filters were employed to reduce levels below 300Hz. This precluded monitoring for lower frequency vocalisations from baleen whales. The acoustic survey was aimed at odontocete whales whose vocal behaviour included sounds in the 300Hz–24kHz range.

The collaboration with BAS and CCAMLR enabled cetacean data to be collected simultaneously with other detailed biological and oceanographic studies from a combination of small- and large-scale study regions. In addition, these surveys aimed to address a comparative lack of data on odontocetes from other research, such as the IWC/IDCR surveys, between 30° and 50°W and particularly north of 60°S (Kasamatsu and Joyce, 1995). A workshop held in Galway in 1995 to outline a programme of non-lethal whale research in the Southern Ocean Sanctuary had also noted that this region was of special interest for cetacean research (Anon., 1995).

METHODS

The hydrophone array and method of deployment from the ship were the same as in previous surveys and are described in more detail in Leaper and Scheidat (1998). The passive acoustic equipment consisted of a hydrophone array towed behind the ship and an automated recording system. The hydrophone was deployed whenever possible such that it did not interfere with any other research whilst the vessel was making way, but had to be recovered at stations where the vessel was stationary. During the 1998/99 survey it was

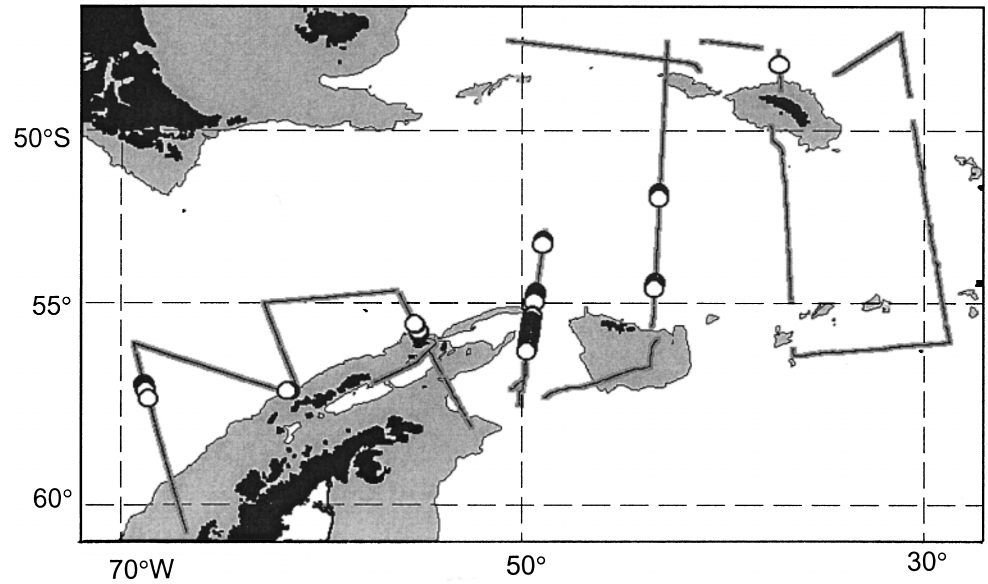

Fig. 2. Acoustic survey track and location of sperm whale detections (open circles) during January-February 2000 IWC/CCAMLR survey. Grey shaded area indicates water depths of less than 1,000m.

deployed successfully alongside an Undulating Oceanographic Recorder (UOR) with no interference to either instrument. The array was towed on a 400m kevlar-reinforced cable and consisted of a 10m long, 30mm diameter, oil-filled, polyurethane tube containing two Benthos AQ-4 elements, 3m apart. Each AQ-4 element had a separate pre-amplifier with 29dB gain and a bandwidth of 200Hz-40kHz. Calibration of the complete array and cable configuration has not yet been conducted. Previous tests using the same pre-amplifier design, but different oil and tube wall material, gave a flat response with a sensitivity of approximately –170dB re 1V/μPa. This is consistent with the hydrophone element manufacturers specification and measurements of preamplifier gain and cable attenuation. Analysis of surface echoes indicated that the array was around 5-6m below the surface at survey speeds of 10 knots.

Signals from the hydrophones were filtered using high pass filters set at 300Hz and further amplified onboard using a differential amplifier with a gain of 20dB. Low pass filters within a *Sony TCD-D10 Pro* Digital Audio Tape (DAT) recorder were used to prevent aliasing for both tape recordings and real time processing. During the 2000 survey, signals were digitised at a sampling rate of 50kHz and a real time monitoring software package (*Rainbow Click*), specially designed to detect and measure bearings to sperm whale clicks, was run continuously whenever the hydrophone was deployed (Gillespie, 1997; Gillespie and Leaper, 1997).

The first stage of the real-time detection system was to digitise the signal and then filter using a 4th order Butterworth filter (Lynn and Fuerst, 1989) set to a band pass of 2-5kHz. These settings were chosen to be optimal for sperm whale detection, with the lower frequency of 2kHz set to reduce false triggers due to the higher frequency components of ship and water noise. The upper frequency of 5kHz was selected to reduce interference from the ship's 12kHz echo-sounder which was running throughout the survey and was a major, but predictable, source of high frequency noise. In addition to digital filters, the software also used a simple noise cancellation algorithm to reduce triggering from ship generated noise sources directly ahead of the hydrophone. This involved applying a time delay equivalent to the propagation time of sound between the two hydrophone elements to the signal from the front element and then subtracting it from the signal from the other element. Even with this noise cancellation, the majority of false triggers were due to ship noise, especially cavitation from the ship's propeller. To reduce processing time and data storage requirements, any possible trigger events from bearings within an 11° cone directly ahead of the hydrophone were rejected. This would only affect the probability that a whale was detected in situations where the whale was vocal for the time that it was both within the 11° cone ahead of the array and within detection range, but subsequently ceased to vocalise for the rest of the time that it was within range as the ship passed.

After filtering and noise cancellation, the programme used a two stage trigger algorithm as described in Gillespie (1997) to identify blocks of data representing possible whale clicks. Bearings to these clicks relative to the axis of the array were then calculated based on the time difference between the arrival of the signal at the two hydrophones (see Leaper *et al.*, 1992). If more than one whale was heard the programme provided a procedure for assigning clicks to individuals using a combination of the relative bearing, amplitude and power spectra properties of each click. The graphical user interface also allowed operator input into this process. Whale location (subject to side-to-side ambiguity) could then be estimated by crossing bearings obtained from different positions along the trackline. The estimate of whale location when it passed abeam of the hydrophone was used for measurement of perpendicular distance. If a whale was silent when it came abeam of the hydrophone then the location closest in time to the estimated time when the whale came abeam was used. For single whales, a simple visual inspection of plots of intersecting bearings was sufficient to enable measurement of perpendicular distance from the trackline. Where several whales were audible at once, an iterative process of visual inspection of plots and assigning bearings to individuals was required to eliminate false intersections of bearings that had yet to be assigned to individual whales. This process involved identifying likely candidate whale locations judging from the number of bearings intersecting at a point and then examining the properties of clicks on these bearings for the likelihood that they came from the same individual. Over short time periods, successive sperm whale clicks from the same individual tend to have similar spectral properties. These characteristics do not appear to indicate permanent unique characteristics, but do nevertheless allow clicks within a continuous sequence to be assigned to an individual (Gillespie and Leaper, 1997). Bearing lines that could not be assigned to an individual whale on the basis of the amplitude and spectral properties of the clicks, or to a location where several lines intersected, were assumed to be from distant whales at the limit of the detection range.

During the 1998/99 survey and in addition to real time monitoring in 2000, a DAT recorder controlled by a personal computer was used to make 30 second recordings every two minutes. These recordings were used to assess the performance of the real time detection system and to allow aural monitoring for tonal calls. Data from the ship's system, including position, depth, vessel speed and heading, true wind speed and direction, and sea surface temperature, were stored for each recording sample.

Calibration tests to investigate the accuracy of bearings obtained acoustically were conducted with sounds from static objects and also using sperm whale vocalisations. There are a number of factors that could result in error in measurement of bearings to vocalising whales. Theoretical accuracy is limited by the timing resolution of the 50kHz sampling rate, especially for bearings close to the axis of the array. In practice, the movement of the ship and array are likely to be the major sources of errors. Lumps of ice or 'growlers', which emitted continuous 'popping' type noises suitable for measuring bearings acoustically, were frequently encountered. For calibration purposes these were assumed to be stationary and a sequence of around 30 bearings was used to estimate the location of the growler. The difference in the measured bearings relative to the calculated bearing to the estimated position was then used to estimate the variance in bearing measurements. The variation within sequences of bearings to vocalising sperm whales was also analysed. These sequences were limited to around one minute duration to reduce the effects of whale movement.

Estimates of effective strip half-width for sperm whales were calculated from the measurements of perpendicular distance using the program DISTANCE (Buckland *et al.*, 1993). Based on the assumption that all whales directly on the trackline were detected, i.e. $g(0) = 1$, estimates of density were then $\hat{D} = n/2wL$ where n was the number of whales detected and L the distance surveyed.

RESULTS

The dates and acoustic effort in kilometres by 10° blocks of latitude are given in Table 1 for each survey. The total effort was 216 hours along 4,180km (2,257 n.miles) of trackline during the 1998/99 survey and 353 hours along 7,292km (3,937 n.miles) of trackline during the 2000 survey. Except for one incident in 1998 when the hydrophone cable was damaged and needed repair, the equipment worked well. It required little attention apart from changing tapes, backing up data files, deployment and recovery of the hydrophone.

Table 1

Acoustic effort (km) by 10 degree blocks.

	70°–60°W	60°-50°W	50°-40°W	40°-30 °W	30°-20°W
1998/99 BAS survey (18 December 1998 - 10 January 1999)					
40°-50° S	0	23	755	0	0
50°-60° S	0	417	946	2039	0
2000 IWC/CCAMLR survey (14 January 2000 - 12 February 2000)					
50°-60° S	165	287	1,742	1,551	323
60°-70 ° S	1,222	702	761	373	166

Detections of sperm whales

The system was optimised for sperm whale surveys and so it is not surprising that sperm whales were the species which was audible for the greatest proportion of the time on both surveys. Detections of sperm whales are summarised in Table 2.

Locations relative to the vessel (subject to side-to-side ambiguity) were obtained for nine out of the 13 sperm whales which were detected on the 1998/99 survey. In one case it was not possible to locate a group of three whales because the hydrophone was only deployed when the whales were already astern of the ship and in another instance the angular separation of the bearings was insufficient to estimate range.

Only one sperm whale was heard on the tapes during the 2000 survey which did not appear on the output of the software. The clicks from this whale were only heard very faintly and so it was assumed to be on the limit of the range of detection. Of the 28 sperm whales detected by the software, perpendicular distances were measured for 24 (86%). Measurement of perpendicular distances was not possible for two whales that were only detected for short periods. These whales were both detected at bearings close to 90° suggesting that they were at a perpendicular distance close to the maximum range of detection. Even if it had been possible to measure ranges to these whales they would likely have been truncated in analysis of perpendicular distances. Distances were not obtained to a further two whales because they were either detected at the start or end of a transect and did not pass abeam. The total acoustic effort and locations of sperm whale detections from the 1998/99 and 2000 surveys are shown in Figs 1 and 2, respectively. Fig. 3 shows the detections of sperm whales from the finer scale surveys around South Georgia in 1998/99. An example of the use of acoustic bearings to estimate locations of whales from one encounter with five individuals is shown in Fig. 4. In Fig. 4 the track of the vessel is represented by the x axis with the y axis indicating perpendicular distances from the trackline. In this example the vessel was travelling at a speed of 5.2ms^{-1} (10.5knots).

There were no visual sightings of sperm whales during 890km of effort in the 1998/99 survey (Leaper and Papastavrou, 1999) and three sightings from the *James Clark Ross* during 2,894km of effort in the 2000 survey (Reilly *et al.*, 2000). There were some periods of acoustic effort where there was no visual effort and vice versa due to weather, daylight and operational constraints. Two of the sightings of sperm whales made during the 2000 survey occurred when the hydrophone was deployed and these were both detected acoustically.

Table 2

Sperm whale encounters.

Date	Time of start of encounter	Latitude	Longitude	Number of whales	Perpendicular distances (km)											
1998/99 BAS survey (18 December 1998 - 10 January 1999)																
18 Dec. 1998	19:25:00	-51.39	-56.54	3	+											
2 Jan. 1999	12:18:02	-53.37	-39.14	1	*											
3 Jan. 1999	15:06:20	-53.58	-38.65	1	5.3											
4 Jan. 1999	09:28:10	-53.71	-38.38	1	5.6											
4 Jan. 1999	09:44:20	-53.67	-38.40	1	3.1											
4 Jan. 1999	09:54:10	-53.65	-38.40	1	4.0											
4 Jan. 1999	15:04:10	-53.56	-38.34	1	2.5											
4 Jan. 1999	15:09:16	-53.56	-38.34	1	0.6											
8 Jan. 1999	16:08:00	-53.25	-44.15	1	5.3											
8 Jan. 1999	17:06:18	-53.25	-44.43	1	1.5											
8 Jan. 1999	17:27:50	-53.25	-44.54	1	1.1											
2000 IWC/CCAMLR survey (14 January 2000 - 12 February 2000)																
25 Jan. 2000	20:22:02	-52.93	-37.21	1	*											
28 Jan. 2000	21:48:02	-56.89	-43.17	1	18											
29 Jan. 2000	20:58:02	-59.43	-43.40	5	1.5	11	28	9	6.9							
2 Feb. 2000	08:50:02	-58.27	-48.96	1	1.4											
2 Feb. 2000	20:30:02	-59.70	-49.33	4	4.8	6.5	7.4	14								
3 Feb. 2000	00:08:02	-60.33	-49.51	2	7.1	+										
3 Feb. 2000	06:36:02	-60.48	-49.55	12	+	6.3	5.9	2.3	1.9	2.9	0.7	5.8	3.8	2.5	*	*
5 Feb. 2000	07:00:02	-60.82	-55.14	1	11											
7 Feb. 2000	04:54:02	-62.30	-61.57	1	2.4											
8 Feb. 2000	12:36:02	-62.15	-68.88	1	1.5											

* No perpendicular distance estimate, because whale was assumed to be close to the limit of detection and sufficient separation of bearings was not achieved.

\+ No perpendicular distance estimate because whale was detected close to start or end of transect.

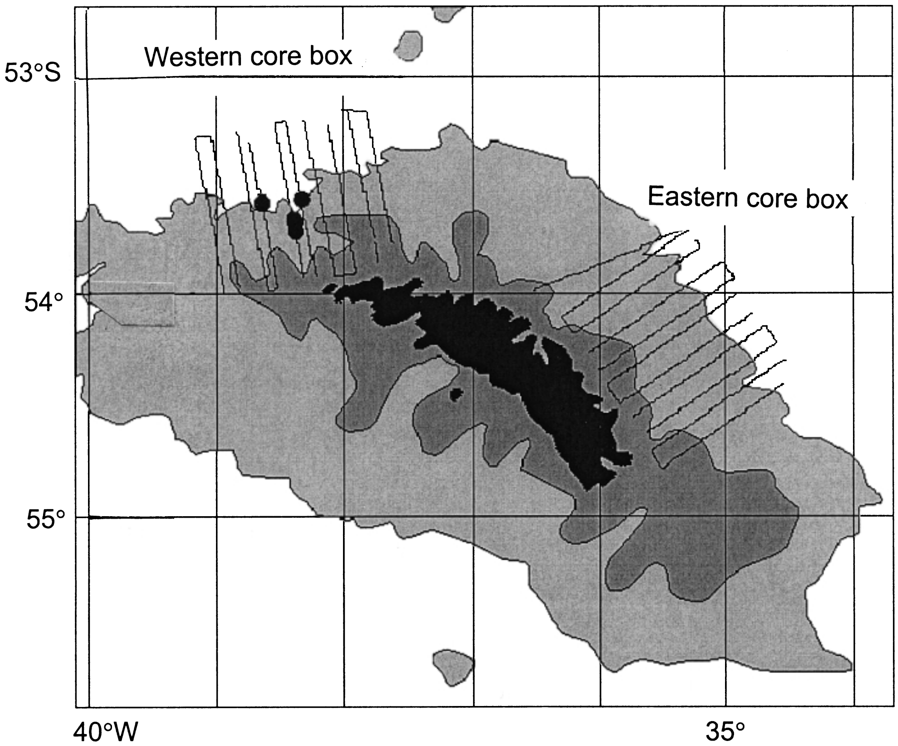

Fig. 3. Survey transects and detections of sperm whales (filled circles) in 'Core Boxes' around South Georgia during 1998/99 BAS survey. Pale shaded area indicates water depths between 200m and 2,000m. Darker shaded area indicates water depths less than 200m.

Localisation of sperm whales

The results of the tests to estimate bearing accuracy showed no significant difference between the variance of bearings obtained to growlers and those to whales, over periods of a few minutes. This suggests that the estimates of mean error in bearings to growlers should give a good indication of the mean error in bearings to whales. Bearing accuracy decreased with increasing wind speed, suggesting that the dominant source of error was movement of the array. RMS bearing errors (close to 90°) were ±1.3° in 14 knots of wind and ±2.3° in 28 knots of wind.

The accuracy of the estimated location for a particular whale depends on the relative angles at which bearings intersect and the movement of the whale between bearings. In contrast to sightings surveys, it is not possible to estimate the location of the whale instantaneously at the point of initial detection, and the most accurate positions are likely to be obtained when the whale is abeam of the hydrophone. Any movement of the whale results in a non-unique or incorrect solution to the intersection of bearings. This is illustrated by the inset in Fig. 4 which shows a progressive change in intersection of bearings, indicating an increase in perpendicular distance over time. This results in some uncertainty in perpendicular distance abeam, even for a single whale. As an example of the likely magnitude of these errors, suppose that the ship is travelling at a speed of 5ms^{-1} and the whale is swimming at 1ms^{-1}. If an angle separation of 30° is required for an estimate of position, the maximum error in perpendicular distance due to whale movement perpendicular to the array would be around 10%. Any vertical component of movement due to diving, which tends to involve the fastest swimming speeds for sperm whales, will be perpendicular to the axis of the array. In the worst case scenario of a whale swimming directly parallel to the trackline, the maximum error for these ship and whale speeds would be 20%. However, these errors still compare well with the level of accuracy obtained from visual surveys (e.g. Thompson and Hiby, 1985) with the additional advantage that there should be no overall bias, and the uncertainty in acoustic measurements could be measured and incorporated in the variance of the estimate of strip width.

Estimate of effective strip width for sperm whales

The two surveys were conducted using the same hydrophone array and recording equipment from the same vessel in overlapping survey areas. The only differences in the equipment between the two surveys were with the real time analysis software which was run in 2000. Only one whale out of 29 was detected aurally on tape but not by the software, suggesting no reason to expect differences in detection ranges between the two surveys. Perpendicular distances were not significantly different between the 1999 ($n = 9$) and 2000 ($n = 24$) surveys (T-test, $p = 0.09$) and so were pooled for the purposes of estimating strip width.

The perpendicular distances measured were distances in three dimensions perpendicular to the axis of the array. Thus, a whale at depth x but directly on the trackline would be assigned to a perpendicular distance of x. Although in many ways it makes sense to express whale densities for deep-diving species in terms of animals per unit volume, the conventional approach of estimating density by area is used here to facilitate comparison with other studies. Given maximum detection ranges of the order of 30km the effect of diving on two-dimensional strip width will result in a small bias. The extent of this bias can be estimated as illustrated in Fig. 5 together with a simple model for diving behaviour. For a whale at a particular depth d, the probability that it will be within a two-dimensional strip of width w but at a greater distance than w from the survey vessel is given by:

$$f(d) = \frac{w - \sqrt{(w^2 - d^2)}}{w}$$

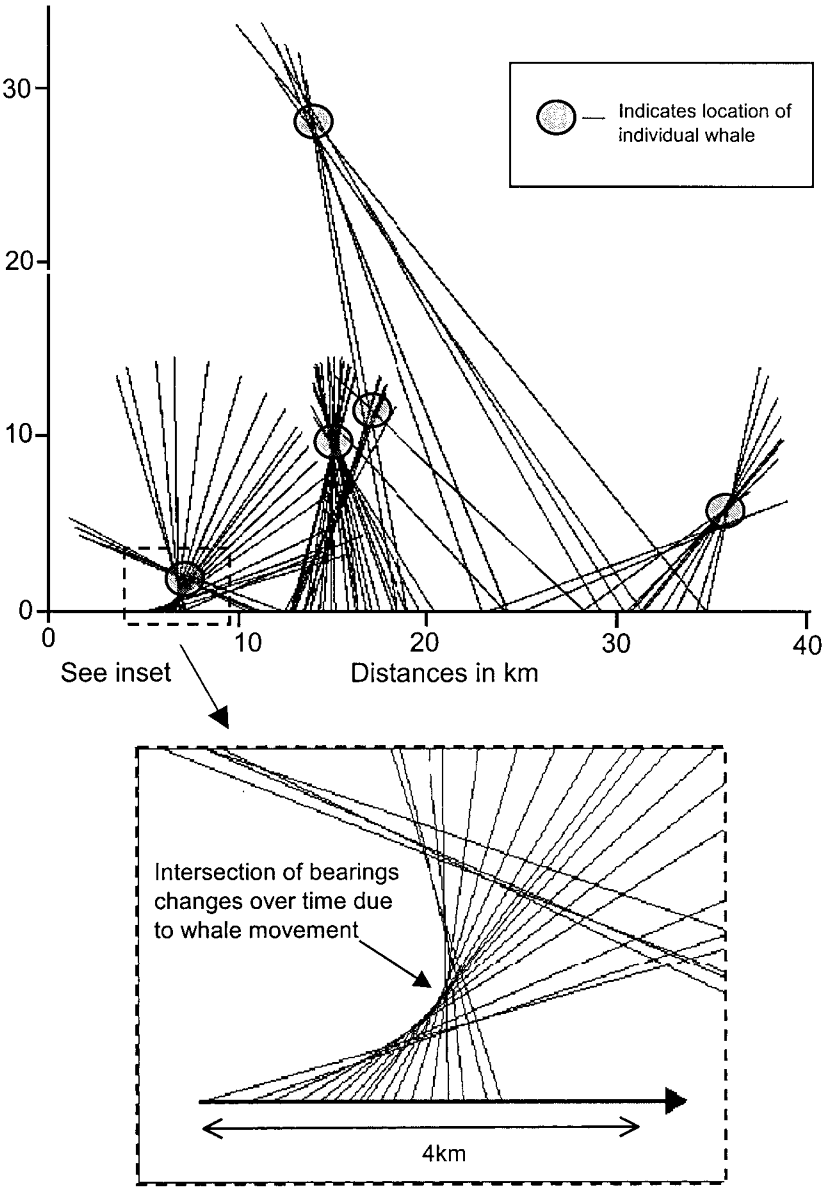

Fig. 4. Plot of bearing lines used to locate five sperm whales during one encounter. Inset shows non-unique intersection of bearings believed to be caused by whale movement. Survey trackline lies along x axis which represents distance travelled by the vessel.

The bias caused by diving behaviour is then the integral over the dive sequence of the product of $f(d)$ and the proportion of time spent at depth d. Results of some trial analyses are shown in Table 3. For the most realistic cases of whales diving to around 1,000m, bias was less than 1% and even for the less realistic cases of whales diving to 3,000m the bias was only 4.5%

Perpendicular distances were truncated at 20km resulting in the loss of one outlying point at 28km. The outlying point at 28km could be the result of location error due to plotting intersecting bearings from different whales, but this is thought to be unlikely. Detection ranges of close to 30km were obtained from several single animals based on the distance travelled until whales were no longer detected. A half normal detection function was selected on the basis of Akaike Information Criterion (AIC) and fitted to the observed distribution of perpendicular distances truncated at 20km, using the program DISTANCE (Fig. 6). This gave an estimated strip half-width of 8.0km (95% CI 6.4-9.9km). It is possible that consideration of variation in source levels and modelling of acoustic propagation and vocal behaviour could result in a detection function with a greater physical significance which could be explored in further analyses. The objective nature of the automated detection system (which includes continuous background noise measurements) should also allow confident pooling of data between surveys, or stratification within a survey according to background noise levels.

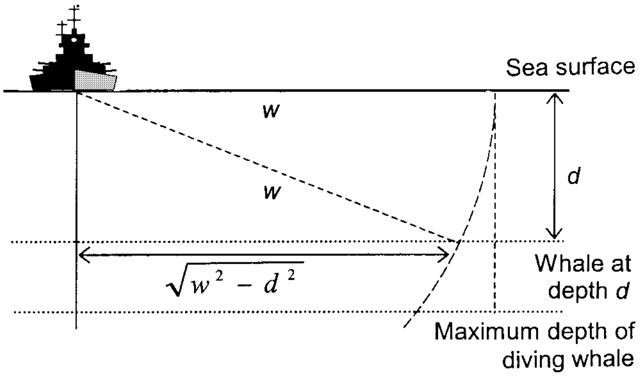

Fig. 5. Cross section view of volume of water surveyed (w = estimated strip half-width).

Table 3

Potential bias due to diving behaviour.

Model assumptions, (w = 8,000m)	Bias
85% of time at 500m, 15% diving between 0 and 500m	0.2%
70% of time at 1,000m, 30% diving between 0 and 1,000m	0.6%
30% of time at 2,000m, 70% diving between 0 and 2,000m	2.2%
10% of time at 3,000m, 90% diving between 0 and 3,000m	4.5%

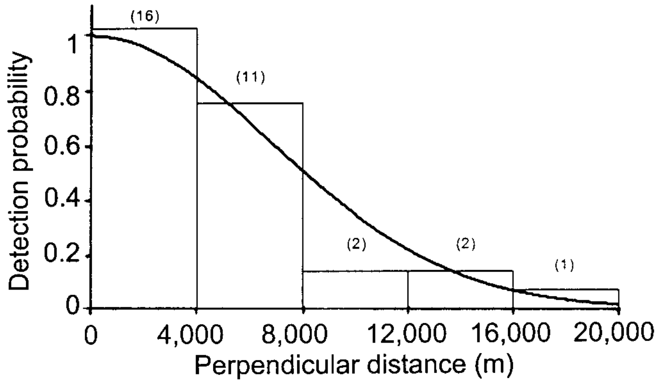

Fig. 6. Detection function for sperm whales. Numbers in brackets indicate number of individual detections.

The location of one sperm whale which was seen at the surface was determined using photogrammetric techniques (Leaper *et al.*, 1999). This particular encounter was of interest because the whale was close (50m) to the trackline and 3,280m ahead of the vessel at the time the start of the dive was observed, although unusually the whale did not fluke up. The intersections of acoustic bearings indicated little whale movement and when the whale came abeam of the hydrophone, 9mins 26secs after diving, the difference in position derived from the video and acoustics suggested a movement of only 300m, i.e. a speed of 0.5ms^{-1}. Vocalisations from this individual were monitored for a further hour. A possible interpretation of the lack of fluke-up, slow swim speed and regular click rate is that the whale was feeding at depths of less than 300m. Although this is highly speculative it does illustrate the potential for combined acoustic and visual observations to collect useful behavioural data during line transect surveys.

Table 4 shows the density estimates derived from the two surveys using the combined strip half-width of $w = 8.0$km (6.4-9.9) and assuming $g(0) = 1$.

Detections of other species

Apart from sperm whales, other acoustic detections which could be positively identified to species included vocalisations from killer whales (*Orcinus orca*), pilot whales (*Globicephala sp.*), southern bottlenose whales (*Hyperoodon planifrons*) and hourglass dolphin (*Lagenorhynchus cruciger*). These are summarised in Table 5. There were also detections of lower frequency moan type calls believed to be from humpback (*Megaptera novaeangliae*) or southern right whales (*Eubalaena australis*) during the 1998/99 survey in the Eastern 'Core Box' off South Georgia. This was the only area where such calls were heard and no lower frequency calls were heard during the 2000 survey. Killer whales and pilot whales make distinctive calls (Taruski, 1979; Awbrey *et al.*, 1982) which were identified from the tape recordings. These species also produce clicks that were detected by the software but could not be used for species identification. For encounters where these species were detected visually and acoustically (around 30% of acoustic encounters) there were never any discrepancies in species identification. However, there is a chance that these species cannot be identified with 100% certainty from acoustic data due to the lack of acoustic studies in the region for comparison. There was one detection of 'rapid click trains' clicks during the 2000 survey that corresponded to a close sighting identified by the visual observers as southern bottlenose whales. Hourglass dolphins were seen close to the hydrophone and simultaneously detected acoustically on eight occasions. However, the properties of the clicks that were detected appeared quite variable and it is difficult to acoustically identify this species with certainty. Table 5 shows the numbers of encounters of each species based on either aural listening to tape, the software, or both. The filter settings reduced the efficiency of the software to detect species with higher frequency vocalisations. This appeared to be the reason for the relatively large proportion (32%) of dolphin encounters that were not detected by the software. However, 55% of encounters were only detected by the software and were not detected aurally from the tapes. This was caused by vocalisations lasting only a few seconds that were detected by the software but occurred during the off-duty cycle of the tape recording system.

Table 4

Estimates of sperm whale density. n = number of whales used for density estimate, = density estimate, whales per 1,000km^2.

	n	Effort (km)	-
1998/99 BAS survey (18 December 1998 - 10 January 1999)			
Western Core Box (South Georgia)	7	822	0.53
Eastern Core Box (South Georgia)	0	863	0
Overall	9	4,199	0.13
2000 IWC/CCAMLR survey (14 January 2000 - 12 February 2000)			
Overall	22	7,292	0.19

The locations of 'dolphin-like' clicks, which were assumed to be from hourglass dolphins, on the 2000 survey are shown in Fig. 7; detections of killer whales are also shown here. Although there were few detections of killer whales, they were not seen without also being detected acoustically while the hydrophone was deployed. This suggests that the acoustic equipment used may be suitable for surveys of this species. However, listening to the tape recordings proved essential for identifying killer whale tonal calls which were not detected by the software. Attempts at making estimates of locations of killer whales by crossing bearings were not successful. This was probably due to either fast swimming speeds or the use of bearings from different individuals.

Plots of the 2000 survey data indicated strong similarities in the distribution of killer whales and sperm whales. To investigate this further the total survey transects were divided into sampling units of contiguous sections of 20km track length. Shorter lengths between the end of a 20km section and the end of the transect were discarded. This resulted in 352 sections. At least one sperm whale was detected on 21 of the sections. There were six sections with detections of killer whales. Sperm whales were also detected on all of these sections. The probability p that all the sections

Table 5

Summary of detections of species other than sperm whale. *A* = detected from aural monitoring of tape recordings only; *R* = detected by the software only; *B* = detected by both software and aural monitoring of tape recordings.

Detection type				Total number of detections
1998/99 BAS survey (18 December 1998 - 10 January 1999)				
Lower frequency moan (baleen whale type call)				7
Hourglass dolphin (confirmed visually)				2
Killer whale (identified by tonal calls)				3
Pilot whale (identified by tonal calls)				3
2000 IWC/CCAMLR survey (14 January 2000 - 12 February 2000)	*A*	*R*	*B*	
'Like hourglass dolphin' (number of separate encounters with sequences of clicks with similar properties to encounters where species identification was confirmed visually)	7	12	3	22
Killer whales (identified by tonal calls on tape)[1]	6	0	1	7
Southern bottlenose whale (confirmed visually)	0	0	1	1
Pilot whale (identified by tonal calls on tape)[2]	1	0	1	2

[1] The one encounter detected by the software also included click sequences. [2] One encounter also included click sequences.

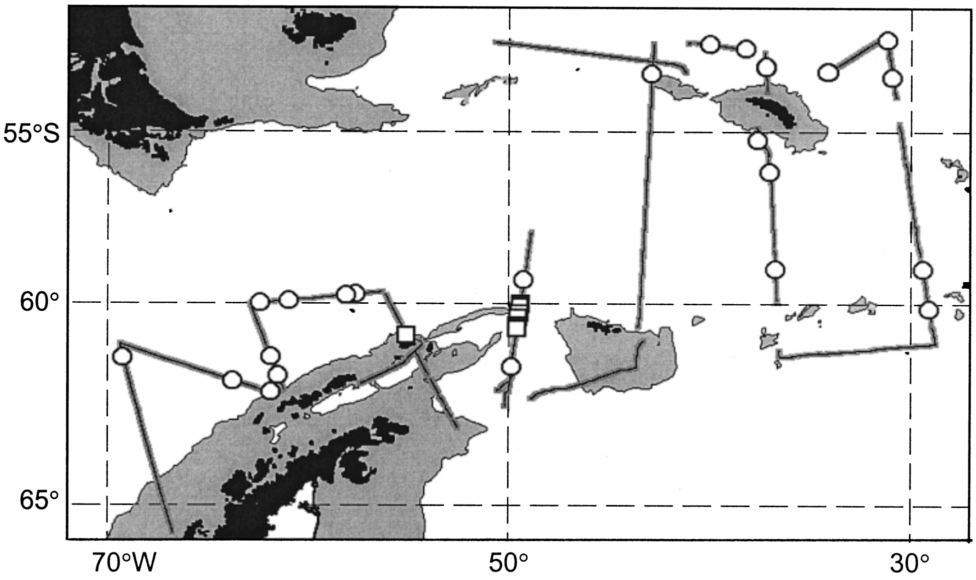

Fig. 7. Locations of dolphin-like clicks (open circles) and killer whales (squares) during 2000 IWC/CCAMLR survey. Grey shaded area indicates water depths of less than 1,000m.

where killer whales were detected also included sperm whales, assuming the distributions of the two species were independent, can be expressed as:

$$p = \frac{21}{352} \times \frac{20}{351} \times ... \times \frac{16}{347}$$

Although this calculation ignores a certain degree of auto-correlation between transect sections for both species, the fact that $p << 0.001$ indicates a significant relationship between the distributions of the two species.

DISCUSSION

The use of the *Rainbow Click* real time monitoring software enabled data to be collected by an almost fully automated system operated by a member of the visual observation team. The weather conditions encountered during the surveys were also more conducive to acoustic work than visual observations, and the amount of acoustic survey effort achieved was more than double the visual effort. The continuous nature of the monitoring also allowed perpendicular distances to vocalising sperm whales to be measured. This had the advantage of enabling analysis of acoustically derived data, using well-developed methods such as the program DISTANCE, in much the same way as for visual sightings. This data format will also simplify entry into a standardised database alongside the visual data from the IWC/CCAMLR survey.

For surveys of sperm whales, the methods used in this study overcome some of the problems described by Thomas *et al.* (1986) of using an array of hydrophones towed behind a ship for cetacean surveys. However, further developments are needed to enable this equipment, and particularly the automated system, to obtain density estimates for other species. Nevertheless, there were greater numbers of acoustic detections of groups of dolphins and killer whales than visual sightings, suggesting that acoustic methods are an effective way of investigating distribution patterns of these species in the Southern Ocean. One feature of the automatic monitoring system of particular value for studies of certain species is the ability to monitor higher frequencies than can be heard aurally. Although it is possible to make recordings at high frequencies and listen to them at slower speeds, this is costly and even more onerous than listening to standard recordings. Software similar to that used in this study could potentially be used to monitor for click type sounds at any frequency depending on the capability of the computer system to sample and process the signals.

The difference between the estimated strip width (8.0km) and maximum range of detection (> 30km) for sperm whales was quite substantial. Qualitative analysis of long sequences of clicks from single whales showed considerable fluctuations in received levels as the signal faded in and out. This was most likely due to changes in propagation characteristics close to the hydrophone, which would not be unexpected for a hydrophone around 6m from the surface. Whale orientation and variation in source levels could also cause fluctuations in received levels. The mean radial distance at which whales at a known location were no longer detected astern of the ship from this study was 10.2km. This is consistent with the effective radial range of detection calculated by Gillespie (1997) using similar equipment from the *Aurora Australis*. Although it would clearly be advantageous to use some kind of depressor to pull the hydrophone to a greater depth, this would be at the expense of greater cost and less portability. The current system with a 400m, 11mm diameter, kevlar reinforced cable appears to be at about the limit of strength for this type of cable and any increase in loading would need to be matched by an increase in cable size. Developments in cable manufacture such as the use of fibre optics may allow use of narrower or stronger cables which would be easier to deploy at depth.

Sperm whales south of the Antarctic Convergence are almost exclusively male. The only report of a female was a single whale caught around South Georgia (Matthews, 1938), and whales at these latitudes are not believed to form groups. However, data from this survey and Gillespie (1997) show concentrations of several whales within a few kilometres of each other. It was not possible to measure precise inter-animal distances from the acoustic locations because of the side-to-side ambiguity. The minimum measured distance was 1.1km, supporting the hypothesis that whales are not in groups but do form concentrated aggregations, presumably for feeding. Four whales was the maximum detected at any one time and it proved possible to separate out the bearings to these with a good degree of confidence. However, if aggregations had been larger, or whales much closer together, it would probably have become impossible to assign locations to individuals. In this case the ‘Cartwheels’ type analysis (Hiby and Lovell, 1989) used by Gillespie (1997) would have been required. Barlow and Taylor (1998) encountered large groups during a survey in the Eastern Pacific and noted problems with estimating group size acoustically. In contrast to perpendicular distance-based methods, the ‘Cartwheels’ analysis does require an estimate of the proportion of time spent vocalising.

The assumption of $g(0) = 1$ is supported by the fact that sperm whales have never been detected visually without being detected acoustically on any of the surveys where this equipment has been used (Leaper *et al.*, 1992; Gillespie, 1997; Leaper and Scheidat, 1998; Rendell *et al.*, 1998). For a detection range of 9km (5 n.miles) and a vessel speed of $5 \mathrm{ms}^{-1}$ (10 knots), a whale on the trackline would need to remain silent for over half an hour to remain undetected. This figure takes into account the 11° cone ahead of the array where signals are rejected. Although longer periods of silence have been observed in mature males in other areas (RL, pers. obs.) these are unlikely to occur on a normal feeding cycle and are probably sufficiently infrequent as to introduce minimal bias.

Vocalisations from several of the sperm whales which were encountered could be monitored continuously for periods of between half and one hour and patterns of click rates allow comparison with data from other more detailed studies such as Gordon *et al.* (1992). In addition, a certain amount of data on diving behaviour could be inferred from positions derived acoustically. Although clearly limited, these observations indicate that combined visual and acoustic surveys can provide data that would not be available using either method on its own. Behavioural data from diving sperm whales coupled with biological and oceanographic data from the ship’s instrumentation whilst underway may prove valuable to a better understanding of sperm whale ecology.

The spatial correlation between sperm and killer whales is in contrast to analyses of IDCR surveys by Kasamtsu and Joyce (1995) who found the overall patterns of sperm and killer whale distribution for the whole Southern Ocean to be substantially different. Co-occurrence of these two species in the South Atlantic has been reported around long-line vessels targeting Patagonian toothfish (*Dissostichus eleginoides*) in the vicinity of South Georgia (Ashford *et al.*, 1996) and the Falkland Islands (Nolan *et al.*, 2000). In those instances it appears that the two species are in the same area because of common prey, but killer whales have also been known to attack sperm whales in other areas (Arnbom *et al.*, 1987). The area in which Ashford *et al.* (1996) noted interactions between sperm whales and long-line fishing vessels is within the western ‘Core Box’ off South Georgia where the highest densities of sperm whales and killer whales were found during the 1998/99 survey.

No attempt has been made in this analysis to calculate overall abundance estimates for sperm whales. Estimation of the variance of $\hat{D}$ will depend on the specification of the area for which the estimate applies and any stratification of that area. It would not be very meaningful to stratify the 2000 survey area purely by latitude and longitude because of the large latitudinal changes in the dominant oceanographic features, such as the sub-Antarctic and Polar fronts across the study region (Orsi *et al.*, 1995). If abundance estimates were required these could be based on the boundaries of the CCAMLR synoptic krill survey area, for which the 2000 survey transects were designed. However, further consideration would need to be given to the level of coverage relative to features that may influence sperm whale distribution.

Further analyses to investigate the influence of the physical and biological environment on the distribution of sperm whales within the Southern Ocean Sanctuary are planned. The spatial scale of the different components of the surveys may prove to be of particular value in these analyses. The 1998/99 survey provided very detailed coverage of the two contrasting ‘Core Boxes’ which may help to better interpret the significance of other variables from the larger scale 2000 survey. This study demonstrates the value of combining acoustic methods with visual surveys. The simple automated acoustic system enabled data to be gathered on species for which there were few visual sightings. This was accomplished without any additional personnel and for very modest costs.

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A note on cetacean observations in the Indian Ocean Sanctuary and the South China Sea, Mauritius to the Philippines, April 1999

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ABSTRACT

Information on cetaceans in the Indian Ocean Sanctuary and the South China Sea is summarised from a cruise carried out from 29 March to 17 April 1999. Ten species were positively identified: finless porpoise, pantropical spotted dolphin, spinner dolphin, sperm whale, melon-headed whale, pygmy killer whale, false killer whale, Cuvier's beaked whale, Bryde's whale and fin whale. Spotted dolphins, melon-headed and pygmy killer whales were sighted around the Island of Borneo and sightings of fin whales and a sperm whale west of the Balabac Strait suggest a possible migration route of these species between the South China Sea and the Sulu Sea. This is the first record of fin whales in the South China Sea.

KEYWORDS: INDIAN OCEAN; ASIA; INCIDENTAL SIGHTINGS; SURVEY-VESSEL; FINLESS PORPOISE; PANTROPICAL SPOTTED DOLPHIN; MELON-HEADED WHALE; PYGMY KILLER WHALE; FIN WHALE; DISTRIBUTION; MIGRATION

INTRODUCTION

In 1979, the International Whaling Commission created the Indian Ocean Sanctuary (IWC, 1980). The Sanctuary consists of those waters of the Northern Hemisphere from the coast of Africa to 100°E (including the Red and Arabian Seas and the Gulf of Oman) and those waters of the Southern Hemisphere between 20°E and 130°E from the Equator to 55°S. Cetacean distribution and movements are relatively poorly documented in this Sanctuary (Leatherwood and Donovan, 1991). This note details cetacean observations made during a cruise from Mauritius to the Philippines in April (*ca* 4,520 n.miles).

METHODS

To facilitate systematic data collection, the data-logging program 'Logger' (Conservation Research Limited) ran continuously throughout the survey on a laptop computer connected to the ship's GPS (a *Furuno* GP-50 satellite navigation system). This program automatically recorded the ship's location every five minutes, provided a continuous visual display of the vessel's track on a map of the area and gave audible warnings when input of environmental data was due. Data concerning the sightings (species identification, group size, behaviour, distance and angle to sighting) were entered manually when a sighting was made.

Table 1

Summary of cetacean sightings in the Indian Ocean Sanctuary and the South China Sea during high effort search status.

Species	Sightings	% Sightings	Individuals	% Individuals	School size
Sperm whale *Physeter macrocephalus*	11	34.4	27	18.4	1-8
Pantropical spotted dolphin *Stenella attenuata*	3	9.4	4	2.7	1-2
Spinner dolphin *Stenella longirostris*	2	6.3	23	15.6	3-20
Melon-headed whale *Peponocephala electra*	3	9.4	22	15.0	3-15
False killer whale *Pseudorca crassidens*	1	3.1	10	6.8	10
Pygmy killer whale *Feresa attenuata*	1	3.1	18	12.2	18
Cuvier's beaked whale *Ziphius cavirostris*	1	3.1	1	0.7	1
Finless porpoise *Neophocaena phocaenoides*	1	3.1	1	0.7	1
Bryde's whale *Balaenoptera edeni*	1	3.1	1	0.7	1
Fin whale *Balaenoptera physalus*	1	3.1	3	2.0	3
Unidentified blackfish	2	6.3	11	7.5	2-12
Unidentified dolphin	4	12.5	25	17.0	1-20
Unidentified baleen whale	1	3.1	1	0.7	1
Total	32	100	147	100	-

Water depths were obtained from a nautical chart and, in more shallow waters, with a *JRC* JFV-8010 Echo Sounder. Sea surface temperature was measured every hour and at all sighting locations. Sea states were estimated according to the Beaufort Scale. Data were collected mainly in 'passing mode', where the vessel did not deviate from the trackline. On several occasions sperm whales were approached in order to obtain photographs of their flukes for natural marking studies. These were later provided to the Silliman University of the Philippines.

All observations were made from the Greenpeace vessel the M/V *Arctic Sunrise* (49.6m) with a bridge platform height of 9m. Dedicated watches ('high effort' search status) were carried out during calm weather (i.e. Beaufort sea states 0-4 and visibility of more than 3 n.miles). Watches began at first light and continued until 1800 hours (an average duration of 12 hours). Two experienced observers were on watch at any one time on each bridge wing searching 90° (with a combined angle of 180°), while the third person was on break. Searching was carried out with the naked eye with occasional scans along the horizon using 7 × 50 reticule binoculars. During poor conditions, opportunistic watches ('low effort' search status) were maintained by the watch officers and the lookouts on the bridge. A debris survey which was conducted daily (involving data collected visually and using a towed fine-mesh) will be reported elsewhere.

RESULTS

The survey began on the 29 March 1999 in Mauritius and finished on 17 April 1999. The cruise track is shown in Appendix 1. Cetaceans were sighted on 12 of the 20 days at sea. 'High search effort' consisted of 1,105 n.miles within the Sanctuary and 441 n.miles within the South China Sea. There were 32 sightings (147 individuals) made during high effort and eight odontocete species and two mysticete species were identified during the survey (Table 1). Cetaceans not positively identified were recorded as either unidentified baleen whale, unidentified dolphin or unidentified blackfish[1]. Environmental data for each sighting are given in Table 2.

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[1] Melon-headed whales (*Peponocephala electra*) are likely to be confused with pygmy killer whales (*Feresa attenuata*) unless seen at close range (Leatherwood *et al.*, 1991).

Table 2

Cetacean sighting records in the Indian Ocean Sanctuary and South China Sea, during high and low effort search status. Sperm whales photographed for individual identification are marked with an asterix.

Date	Species	Number	Sea Surface Temperature (ºC)	Depth (m)	Latitude, longitude	Effort
Indian Ocean Sanctuary						
30 Mar. 1999	Sperm whale	4	27.5	4,000	19.05°S, 60.52°E	High
	Sperm whale	1	27.5	4,000	19.05°S, 60.52°E	High
	Sperm whale	3	27.5	4,000	19.03°S, 60.58°E	High
	Sperm whale	1	27.5	4,000	19.01°S, 61.06°E	High
4 Apr. 1999	Dolphin	1	28.0	4,810	13.40°S, 80.09°E	High
5 Apr. 1999	Bryde's whale	1	28.0	4,311	12.50°S, 82.54°E	High
6 Apr. 1999	Dolphin	8	-	2,828	11.00°S, 88.52°E	Low
7 Apr. 1999	Dolphin	1	-	-	10.36°S, 90.26°E	Low
8 Apr. 1999	Cuvier's beaked whale	1	26.5	3,759	09.19°S, 95.08°E	High
	Sperm whale	1 (calf)	26.5	3,759	09.18°S, 95.11°E	High
	Sperm whale	1	26.5	3,759	09.18°S, 95.12°E	High
	Dolphin	2	26.5	3,759	09.16°S, 95.16°E	High
	Dolphin	20	26.5	4,632	09.06°S, 95.54°E	High
10 Apr. 1999	Sperm whale	8	27.5	5,651	07.18°S, 102.02°E	High
	Sperm whale	3	27.5	5,651	07.17°S, 102.02°E	High
	Sperm whale*	2	27.5	5,651	07.16°S, 102.05°E	High
	Sperm whale	2	27.5	5,651	07.17°S, 102.06°E	High
12 Apr. 1999	Spotted dolphin	2 (1 juvenile)	29.5	25	01.45°S, 107.22°E	High
	Blackfish	2	28.8	35	00.45°S, 107.44°E	High
South China Sea						
13 Apr. 1999	Spinner dolphin	20	28.9	29	02.20°N, 109.34°E	High
	Spotted dolphin	1	28.9	29	02.20°N, 109.34°E	High
	Melon headed whales	4	29.5	50	02.45°N, 110.09°E	High
	Melon headed whales	3	29.5	50	02.46°N, 110.10°E	High
	Blackfish	12	28.7	60	04.06°N, 112.04°E	Low
	Finless porpoise	1	28.7	68	04.11°N, 112.12°E	High
14 Apr. 1999	Dolphin	2	28.7	90	04.22°N, 112.28°E	High
	Melon-headed whales	15	28.7	116	04.29°N, 112.39°E	High
	Spotted dolphin	1	28.7	116	04.29°N, 112.39°E	High
	Pygmy killer whales	18	28.7	116	04.29°N, 112.40°E	High
	Blackfish	9	28.7	116	04.30°N, 112.40°E	High
	Blackfish	2	30.7	100	04.47°N, 113.02°E	Low
15 Apr. 1999	Sperm whale*	1	30.4	1,554	07.17°N, 115.32°E	High
	Fin whale	3	30.4	1,554	07.32°N, 115.45°E	High
	False killer whales	10	30.0	2,414	08.01°N, 116.07°E	High
	Spinner dolphins	3 (1 juvenile)	30.0	1,100	08.14°N, 116.18°E	High
16 Apr. 1999	Dolphin	4	29.5	800	12.13°N, 119.01°E	Low
	Baleen whale	1	28.3	3,600	13.44°N, 119.50°E	High

DISCUSSION

A number of authors have previously reported on the distribution of cetaceans in the Indian Ocean: Keller *et al.* (1982); Wray and Martin (1983); Leatherwood *et al* (1984); Kasuya and Wada (1991); Reeves *et al.* (1991); Robineau (1991); Corbett *et al.* (1994); Eyre (1995); Ballance and Pitman (1998); Leatherwood *et al.* (1991). Over forty species are known from the Indian Ocean Sanctuary (IWC, 1980). Similarly, a number of reports have been published about cetacean species occurring in Indonesian waters where about 25 species occur (Leatherwood *et al.*, 1984; Perrin *et al.*, 1995; Rudolph *et al.*, 1997; Beasly and Jefferson, 1999). The present survey adds to the data available from this region, matching precise species location, depth and temperature. It should be seen as part of an ongoing effort to collect such data from platforms of opportunity, ultimately to help determine distribution, migration patterns and critical habitat parameters. Of particular interest from the study were the following: (1) although finless porpoises are generally found in the lower courses of rivers and in coastal waters, our sighting 73 miles offshore in the South China Sea agrees with previous sightings of finless porpoises in the middle of the East China Sea far from shore but in shallow waters (Kasuya, 1999); (2) the sightings of melon-headed whales, pygmy killer whales and pantropical spotted dolphins around Borneo are the first confirmed for these waters (c.f. Beasly and Jefferson, 1999), although not unexpected given their distribution and presence in surrounding waters; (3) our sighting of fin whales is the first record in the South China Sea; and (4) our sightings suggest that the Balabac Strait might represent a migration route for sperm whales and fin whales between the Sulu Sea and the South China Sea.

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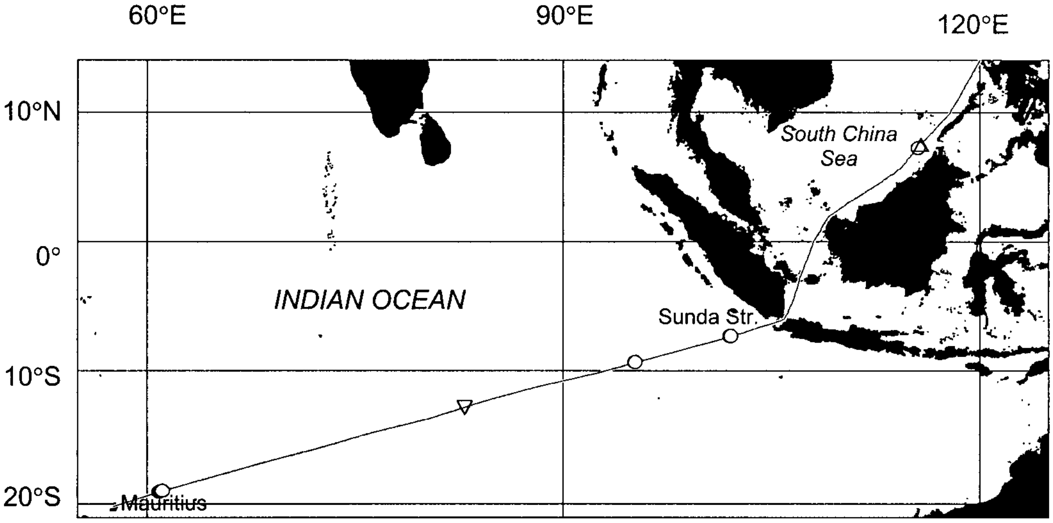
Appendix 1

SURVEY TRACK AND SIGHTINGS OF LARGE WHALES



Key: Sperm whale (open circles); Bryde’s whale (point down triangle); Fin whale (point up triangle).

Population size and residency patterns of northern bottlenose whales (*Hyperoodon ampullatus*) using the Gully, Nova Scotia

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ABSTRACT

A population of northern bottlenose whales (*Hyperoodon ampullatus*) uses the Gully, a submarine canyon off the coast of Nova Scotia, Canada. Eleven years of photo-identification records has permitted estimation of population size using mark-recapture techniques. The population estimate was small (133 individuals, 95% CI = 111-166 from left side identifications; 127 individuals, 95% CI = 106-160 from right side identifications). The population was not closed, with the combined mortality, mark change and emigration rate estimated at 13% per year for left side identifications (95% CI = 9-17) and 14% for right side identifications (95% CI = 10-18). There was no significant increase or decrease in the population size between 1988-1999 (change in population size: left side: –0.13% per year, 95% CI = -3.4 to 3.9; right side: –0.43% per year, 95% CI = -4.5 to 3.1). The sex ratio was roughly 1:1, with equal numbers of sub-adult and mature males. Over the summer field season, individuals emigrated from, and re-immigrated into the Gully, spending an average of 20 days within the Gully before leaving (left side identifications 19 days, SE = 17; right side identifications 23 days, SE = 10). Approximately 34% of the population was present in the Gully at any time. Individuals of all age and sex classes displayed similar residency patterns although there were annual differences as individuals spent less time in the Gully in 1996 than in 1990 and 1997. Sighting rates were similar in all years with extensive fieldwork, indicating little variability in the number of whales in the Gully each summer. Accurate estimates of population size and residency patterns will be useful in determining the regulations and required coverage for a marine protected area in the Gully.

KEYWORDS: MARK-RECAPTURE; PHOTO-ID; TRENDS; POPULATION ASSESSMENT; NORTHERN BOTTLENOSE WHALE

INTRODUCTION

Northern bottlenose whales (*Hyperoodon ampullatus*) are routinely found in the Gully, a submarine canyon off the coast of Nova Scotia, Canada, near the southern and western limits of the species' range. The number of whales in this area has been reduced in the past; whalers removed 87 northern bottlenose whales from the Gully and surrounding area from 1962 to 1967 (Reeves *et al.*, 1993). Currently, potential threats are posed by oil and natural gas development near the canyon (Whitehead *et al.*, 1997a; Hooker, 1999). The Gully has recently been declared a 'Pilot Marine Protected Area' by the Canadian Department of Fisheries and Oceans, partially to protect northern bottlenose whales, although no boundaries or regulations have yet been established.

A small number of northern bottlenose whales are consistently found in the Gully (Whitehead *et al.*, 1997a), although the extent to which bottlenose whales depend on the Gully has not been specifically studied. This group of bottlenose whales has been declared a 'vulnerable' population by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC; Whitehead *et al.*, 1997a) although the genetic isolation of this group has not yet been studied in detail. This paper seeks to (1) evaluate the size of the Gully population and investigate any trends in population growth; and (2) examine the reliance of northern bottlenose whales on the Gully canyon.

METHODS

Field work and photographic catalogue

Photographs of the dorsal fin and surrounding flank of northern bottlenose whales were taken in the deep water areas of the Gully (43°30'-44°30'N, 58°30'-60°00'W) during the summers of 1988-1999 from sailing vessels with auxiliary diesel engines. Time spent in the field varied from only a few days in 1991 and 1992 to a few months in 1990, 1996 and 1997; in 1991 and 1992 sighting conditions were poor (Table 1). Sightings were defined as continuous observations of whales at the surface; a sighting was considered ended when 10 minutes had passed with no whales observed at the surface.

Photographs of both left and right sides of the whale were taken when they were within approximately 30m of the boat, although most of the better quality photographs were taken when the whales were within 15m. Except in 1999, attempts were made to photograph all individuals in the group, irrespective of obvious markings on the individual. Photographs were taken throughout the encounter, whether or not photographs had already been taken of the individual.

Black and white negatives were examined on a light table with a 10x magnifying loupe. All negatives were assigned a qualitative quality rating (Q-value) from 1 to 6 based on focus, exposure, angle of the fin relative to the negative plane and the proportion of the frame filled by the fin (similar to Arnbom, 1987), with Q-6 being the highest quality. Q-values were independent of the markings on the individual. Only photographs of $Q \geq 2$ could be assigned an identification number. Quantitative analysis of the marks visible in each quality category indicated that only photographs of $Q \geq 4$ contained sufficient information to mark animals and permit recapture between years (Gowans and Whitehead, 2001).

The highest quality negative of each individual in each year was printed and the photographs were compared within years and between years. If a photograph matched an individual present in the catalogue, then that photograph and

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Table 1

Yearly distribution of field work in the Gully (43°30'N-44°30'N; 58°30'W-60°W) and sightings rate, during good sighting conditions (daylight hours (0500 to 2000hrs), Beaufort < 4 and visibility > 500m).

Year	Dates in field	No. search hours	No. sightings	Sighting rate/ hour searching	Sighting rate SE
1988	8-21 Jul.; 25 Jul.-6 Aug.	30	7	0.23	0.088
1989	16-30 Jul.; 1-15 Aug.	170	57	0.34	0.044
1990	14-28 Jun.; 2-18 Jul.; 25 Jul.-12 Aug.	238	125	0.53	0.047
1991	23-26 Jul.	0	0	-	-
1992	24-28 Jul.	0	0	-	-
1993	10-23 Jul.	78	54	0.69	0.094
1994	31 Jul.-18 Aug.	84	25	0.29	0.060
1995	20 Aug.-2 Sep.	31	11	0.35	0.11
1996	7-25 Jun.; 4-21 Jul.; 27 Jul.-12 Aug.; 19 Aug.-2 Sep.	330	172	0.52	0.040
1997	7-23 Jun.; 1-19 Jul.; 24 Jul.- 6 Aug; 10-27 Aug.	304	157	0.52	0.041
1998	12-31 Jul.; 6-23 Aug.	181	107	0.59	0.057
1999	6-26 Jul.; 3-23 Aug.	255	136	0.53	0.046
All		1,701	851	0.50	0.017

all other associated negatives were assigned to the whale's identification number. If not matched, the individual was given a new number and added to the catalogue. Photographic collections for left and right sides were maintained separately, although some identifications from different sides could be linked. The negative collection contained 12,563 negatives that were assigned an identification (Table 2).

Table 2

Summary of photo-identification data ($Q \geq 2$) by year.

		No. individuals identified by left fin photographs		No. individuals identified by right fin photographs	
Year	No. of frames	All individuals	Reliably marked individuals	All individuals	Reliably marked individuals
1988	123	18	12	19	13
1989	1,202	109	56	96	53
1990	3,116	171	81	167	74
1991	27	8	5	5	3
1993	549	46	17	53	26
1994	370	54	20	43	20
1995	82	14	6	17	12
1996	1,751	94	54	86	47
1997	1,531	99	57	90	58
1998	2,404	74	42	68	40
1999	1,409	60	41	56	36

Gowans and Whitehead (2001) found that while all individuals possessed marks that could be used for photo-identification, changes in certain marks can affect re-identification of many individuals over time. However, in their assessment of mark changes they found that notches on the dorsal fin, indentations on the back and 'mottled patches' showed no evidence of mark loss over nine years (Gowans and Whitehead, 2001). Therefore all analyses which spanned more than one year, have been conducted only on those individuals (hereafter called 'reliably marked'). To calculate the proportion of the population that was reliably marked, the number of photographs ($Q \geq 4$) containing individuals with reliable marks was divided by the total number of photographs ($Q \geq 4$). This calculation was performed separately for each year when more than one month was spent in the field (1989, 1990, 1996 and 1997) and for left and right sides. The mean and standard error were calculated and the overall proportion was then used to scale the population estimate.

Northern bottlenose whales show sexual dimorphism in the shape of their melon (Gray, 1882). Photographs of the melons, linked to identification photographs, were used to classify individuals as either female/immature male, sub-adult male or mature male. Few individuals in the population showed signs of maturation (Gowans *et al.*, 2000) and individuals were assigned to the age/sex category of their ultimate catalogue identification.

Sighting rate

The rate at which northern bottlenose whales were encountered was calculated from the number of sightings divided by the hours spent searching when conditions were good (i.e. daylight hours from 05:00 to 20:00, Beaufort sea state < 4, visibility > 500m). The sighting rate was calculated separately for each year and for all years combined. Assuming that the sightings were independent and followed a Poisson distribution, approximate standard errors were calculated by dividing the sighting rate by the square root of the number of sightings. As the sightings may not have been independent, the standard errors may be an underestimate of the true variability.

Population size and trends

To investigate whether the population was open or closed (to immigration, emigration, mortality or birth) a discovery curve was plotted. The cumulative number of identified individuals (identified by left fin photographs) was plotted against the cumulative number of high quality left fin photographs. The cumulative number of individuals was also plotted for only reliably marked individuals.

Population size and trends were estimated separately for left and right side identifications based on all $Q \geq 4$ photographs of reliably marked individuals using the POPAN module of SOCPROG 1.2 (developed in MATLAB by HW, programs available at: *http://is.dal.ca/~whitelab/index.htm*) with calendar years as units. Three models were fitted to the population estimates using the Akaike Information Criterion (AIC) to determine which model best described the population (see Appendix 1 for model details). Maximum-likelihood methods, conditioned on the first capture, were used to estimate population parameters of each model. The three models were:

(1) 'Closed' (Schnabel): population has no mortality, birth, immigration or emigration;

(2) 'Mortality': population remains the same with mortality balanced by birth (mortality includes permanent emigration or mark change that prevents recapture and birth includes permanent immigration or mark change that causes a previously identified animal to be identified as a new animal);
(3) 'Mortality + trend': population grows or declines at a constant rate.

Profile likelihood support functions in which other parameters were maximised were used to estimate 95% likelihood confidence intervals for each parameter (Edwards, 1992). As there were few permanent associations (Gowans *et al.*, In press) the assumption of independence was not violated when estimating confidence regions using likelihood methods (Edwards, 1992). Jolly-Seber methods of calculating the population size, mortality/emigration and birth/immigration separately for each year were inappropriate for this dataset, as this method estimates many different parameters resulting in extremely inaccurate estimates (Jolly, 1965).

Age and sex structure

The population size of each age and sex class was estimated and modelled as described above for the entire population. The proportion of the population which was both sexed and reliably marked was calculated by dividing the number of melon photographs linked to a reliably marked fin identification photograph by the number of melon photographs linked to any fin identification. The proportion was calculated separately for each class in each year (1990, 1996 and 1997: years with two months in the field and many melon photographs taken) and then averaged. The estimated number of reliably marked sexed individuals was then scaled to calculate the estimated number of sexed individuals in the population.

Residency in the Gully

The residency of individuals in the Gully was investigated by calculating lagged identification rates. The lagged identification rate for a particular lag tau (τ) is the probability that an individual identified at any time 0 is re-identified in a photograph taken at τ units later (Whitehead, in press):

$$R(\tau) = \frac{P(\tau)}{N} \qquad (1)$$

where:

τ = time lag;
R(τ) = lagged identification rate for τ;
P(τ) = probability individual is still in the Gully after τ;
N = number of individuals in the Gully.

Lagged identification rates were estimated from:

$$\hat{R}(\tau) = \frac{\sum_i \sum_{j:t_j = t_i + \tau} m_{ij}}{\sum_i \mathrm{n}_i \sum_{j:t_j = t_i + \tau} n_j} \qquad (2)$$

where:

n_i = the number of individuals identified on occasion i;
m_{ij} = number of individuals identified on both occasions i and j;
t_i = time of identifications at occasion i.

The maximum lag (τ) between photographs considered was 100 days, which was greater than the number of days in a single field season. Individuals did not have to be reliably marked to be included in these analyses as marks were unlikely to have experienced sufficient change to preclude re-identification within 100 days (Gowans and Whitehead, 2001). Mortality and birth rates were considered to be zero in these analyses as few births or deaths were likely over the 100-day sampling period. Three models of residency were fitted to the residency rate data using AIC methods to determine the best model. Jack-knife techniques (in which data from each date were sequentially eliminated from the dataset) were used to calculate 95% confidence interval error bars and standard errors for each model parameter. The three models were:

(1) 'Closed' (no changes in the individuals present in the Gully):

$$R = 1/N \qquad (3)$$

(2) 'Emigration' (individuals could leave the Gully, but never return):

$$R = \left(\frac{1}{N}\right)^{\frac{-\tau}{I}} \qquad (4)$$

(3) 'Emigration and re-immigration' (individuals could enter and leave the Gully, then re-enter the Gully; Whitehead, 1990):

$$R = \frac{Oe^{-\tau(1/O + 1/I)} + I}{(I + O)N} \qquad (5)$$

where:

N = number of individuals in the Gully;
I = mean time spent inside the Gully;
O = mean time spent outside the Gully.

Lagged identification rates were calculated and models fitted for each age and sex class separately and for each year with more than two months spent in the field. The proportion of individuals in the Gully at any given time was calculated by dividing the estimated number of whales in the Gully by the total estimated population size.

RESULTS

Sighting rate

The sighting rate varied by a factor of about 2.5 between years (Table 1), although all years with extensive field effort (1990, 1996 and 1997) had similar sighting rates, revealing relatively small levels of inter-annual variability in the mean number of whales in the Gully. The sighting rate was low in 1988, as much of the search effort was spent in areas further north than those in which northern bottlenose whales were typically found.

Population size and trends

The discovery curve indicated that new individuals continue to be recruited to the population throughout the study period, especially if individuals with unreliable marks were included (Fig. 1). There was some levelling off in the discovery curve of reliably marked individuals in the last few years of the study, although new reliably marked individuals were sighted each year. New recruits to the population may represent births, immigration into the population, mark change or captures in subsequent years of individuals which had been previously unphotographed. Within a single year the population was not closed as new individuals were continually identified throughout each field season, even in the long field seasons.

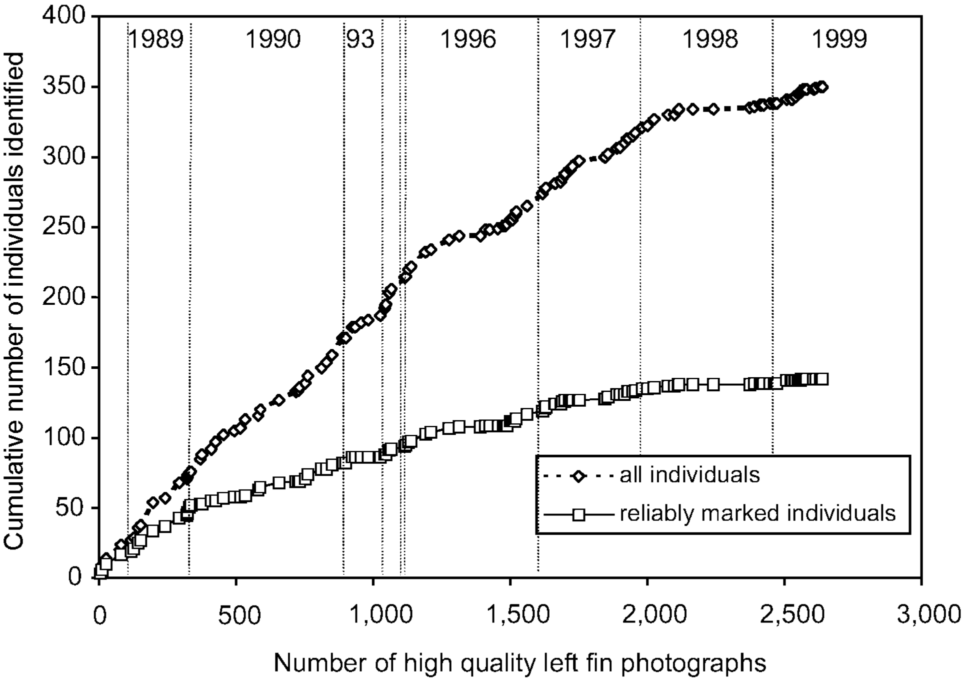

Fig. 1. Discovery curve showing the number of new individuals identified each day. An open population is indicated by the failure of the curves to reach an asymptote even within a single field season.

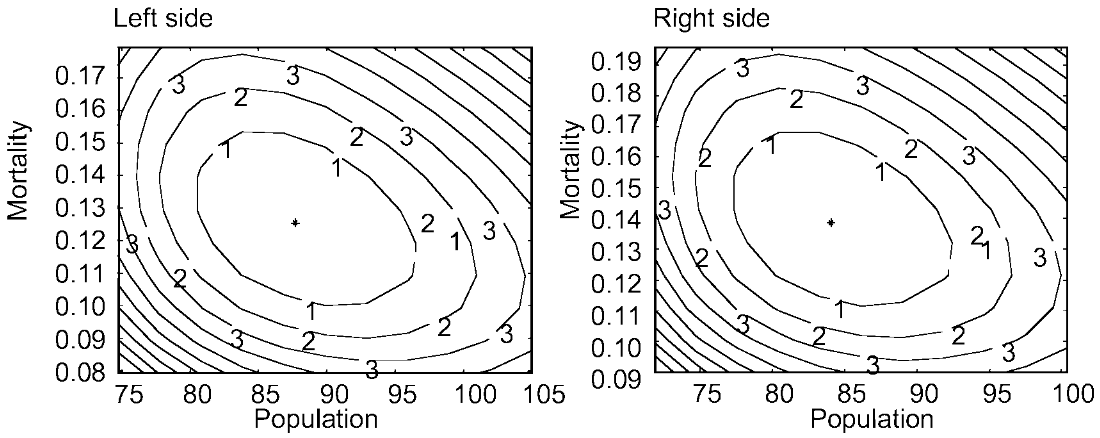

Fig. 2. Support surface contours for estimates of population size and mortality rate of reliably marked individuals, based on mortality model. Support function values less than two approximate the 95% CI region. * Indicates maximum-likelihood estimate.

Table 3

Population estimates for all reliably marked individuals (95% likelihood confidence intervals in brackets). Best-fit models based on Akaike Information Criterion (AIC) are given in *italics*.

Dataset	Model	Population estimate	Mortality (% per year)	Trend (% per year)	AIC
Left side (*n*=147)	Closed	151 (134-174)	-	-	760
	Mortality	*88* *(79-109)*	*13* *(9-17)*	-	*682*
	Mortality + trend	88 (78-101)	13 (9-17)	- 0.13 (-3.4- + 3.9)	684
Right side (*n*=146)	Closed	153 (135-176)	-	-	763
	Mortality	*84* *(75-97)*	*14* *(10-18)*	-	*673*
	Mortality + trend	84 (75-97)	14 (10-19)	-0.45 (-4.5- + 3.1)	675

Of the three models tested to describe the population (closed, mortality, mortality + trend), the mortality model fitted best (Table 3). The mortality + trend model fitted the data no better than the simpler mortality model, although a small non-significant population decline was indicated by the model. Based on the mortality model, the population

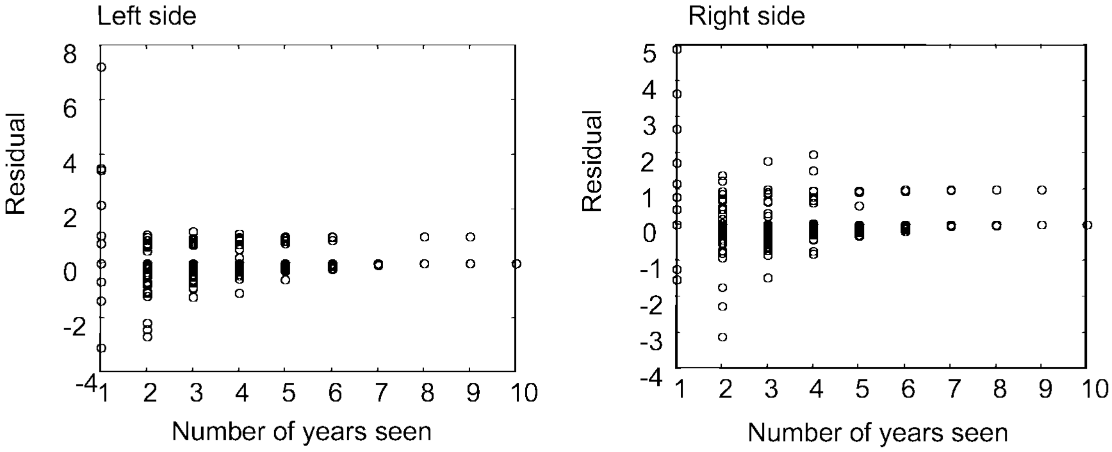

Fig. 3. Residual difference between the expected and observed number of individuals (based on mortality model) with each identification history plotted against the number of years identified for that identification history.

Table 4

Population estimates of reliably marked individuals within each age and sex class (95% CI). Results were for right side identifications, however, the left side results were similar. Best-fit models based on Akaike Information Criterion (AIC) are given in *italics*.

Dataset	Model	Population estimate	Mortality (%)	AIC	Population of sexed individuals (95% CI)
Female/immature male (*n*=45)	Closed	42 (36-52)	-	272	-
	Mortality	*31* *(27-38)*	*7.9* *(3.2-14)*	*257*	*57 (45-77)*
Sub-adult male (*n*=17)	Closed	18 (13-28)	-	70	-
	Mortality	*15* *(13-21)*	*12* *(1.1 - 30)*	*67*	*22 (16-39)*
Mature male (*n*=25)	Closed	25 (21-32)	-	162	-
	Mortality	*18* *(15-22)*	*6.7* *(2.5-13)*	*145*	*27 (19-39)*

estimate of reliably marked individuals was 88 (for left side identifications) or 84 (right side identifications). The estimated mortality, emigration and mark change rate was 13% per year (left side) and 14% per year (right side). Support surfaces indicate the 95% CI of the estimation of the population size and mortality rate (Fig. 2). The population estimate of reliably marked individuals (using the mortality model) ranged from 79-101 individuals (left side) and 75-97 individuals (right side; Table 3). The overall percentage of the population that was reliably marked was estimated to be 66% (5% SE) for all photographs (left side photographs 61%, SE = 6%; right side photographs 69%, SE = 3%). Therefore, the total number of individuals in the population was estimated to be 133 (95% CI = 111-166) and 127 (95% CI = 106-160) for left and right side identifications respectively.

When using mark-recapture analysis to estimate population size, the capture probabilities must not be heterogeneous, with some individuals more identifiable than others, which could lead to negative bias in the population estimate (e.g. Hammond, 1986; 1990). To test for heterogeneity, the residual differences between the observed identification histories and the expected histories (from the fitted model) were plotted against the number of years observed (Fig. 3), with a U-shaped curve indicating heterogeneity (Cormack, 1985). This did not occur when the mortality model was fitted indicating that particular members of the population were not much more or less likely to be identified in the Gully in any year.

Age/sex structure

Data for all age/sex classes showed best fit with the mortality model (Table 4). However, there were insufficient data to test the mortality + trend model on these datasets. Some heterogeneity was observed in the residual plots (not shown), indicating that these age/sex class estimates may be negatively biased. The combined estimated number of individuals in each age and sex class was lower than the estimated total population size as there were some individuals in the population that had not been sexed (Table 4). Estimated mortality rates for each of the age/sex classes were lower than for the whole population (Table 3 and 4). However, the mortality rates of individuals would be expected to be biased downwards since they were more likely to have been sexed if they had survived long-term. The ratio of female/immatures to males (sub-adult and mature combined) was close to parity (1.06:1) for the total estimated population, indicating that there were slightly more female/immatures than the combined numbers of maturing and mature males, which was not surprising as some immature males were included in the female/immature class. The ratio of sub-adult males to mature males was (1:1).

Table 5

Estimated residency parameters (±SE) for all individuals in all years (Q≥4). Best-fit models based on Akaike Information Criterion (AIC) are given in *italics*.

Dataset	Model	Estimated number of individuals in Gully at given time	Mean number of days whales remain in the Gully	Mean number of days whales remain outside of the Gully	AIC
Left side (*n*=346)	Closed	81±21	-	-	7,873
	Emigration	52±12	37±10	-	7,750
	Emigration and re-immigration	*44±5*	*19±17*	*62±272*	*5,736*
Right side (*n*=313)	Closed	78±9	-	-	6,685
	Emigration	49± 6	35 ± 8	-	6,568
	Emigration and re-immigration	*44±6*	*23±10*	*104±113*	*6,564*

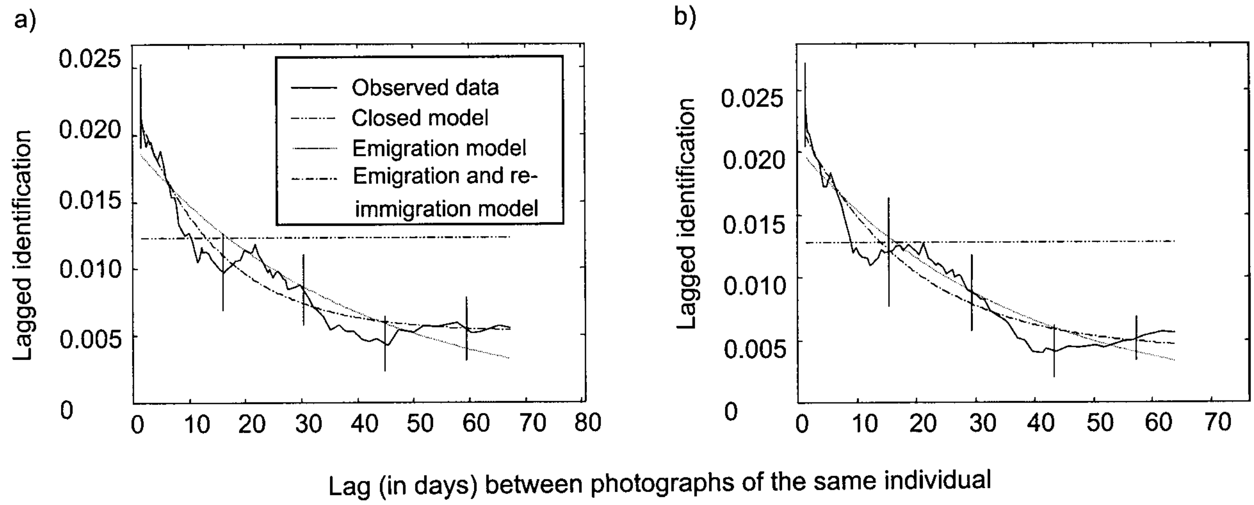

Fig. 4. Lagged identification rate (probability of re-identifying animal after a certain time lag) of northern bottlenose whales in the Gully for (a) left side identifications and (b) right side identifications. Vertical lines are jack-knife error bars.

Residency

The emigration and re-immigration model best described the data, indicating that, within a summer, individuals may enter, leave and re-enter the Gully (Table 5 and Fig. 4). On average, there were 44 individuals in the Gully at any given time (33.1% of the population) and individuals resided in the Gully for approximately 20 days (19 days by left side identifications and 23 days by right side identifications). The standard error of the estimate of the residency period outside of the Gully was large in comparison to the actual estimate, which could indicate that individuals spend variable time periods outside the Gully and/or that the summer field seasons have not been able to sample a large number of exits from and re-entries to the Gully.

Age/sex class differences

The emigration and re-immigration models best described all three datasets (Table 6 and Fig. 5). Based on the emigration and re-immigration model, female/immature males and mature males spent longer in the Gully than sub-adult males, but the standard errors for these estimates were large (Table 6). Similarly, the standard errors on the

Table 6

Estimated residency parameters (±SE) for each age/sex class based on left fin identifications in all years (Q≥4). Best-fit models based on Akaike Information Criterion (AIC) are given in *italics*.

Age/sex class	Model	Number of individuals in Gully at given time	Mean number of days whales remain in the Gully	Mean number of days whales remain outside of the Gully	AIC
Female/immature male (*n*=91)	Closed	25±3	-	-	2,845
	Emigration	*16±2*	*36±16*	-	*2,790*
	Emigration and re-immigration	15±2	30±16	236*	2,791
Sub-adult male (*n*=17)	Closed	10±2	-	-	386
	Emigration	7±3	57±64	-	384
	Emigration and re-immigration	*4±2*	*7±4*	*18±18*	*377*
Mature male (*n*=33)	Closed	14±1	-	-	1,445
	Emigration	11±5	60±10	-	1,431
	Emigration and re-immigration	*9±2*	*22±35*	*35**	*1,430*

* SE very large (over 1 million).

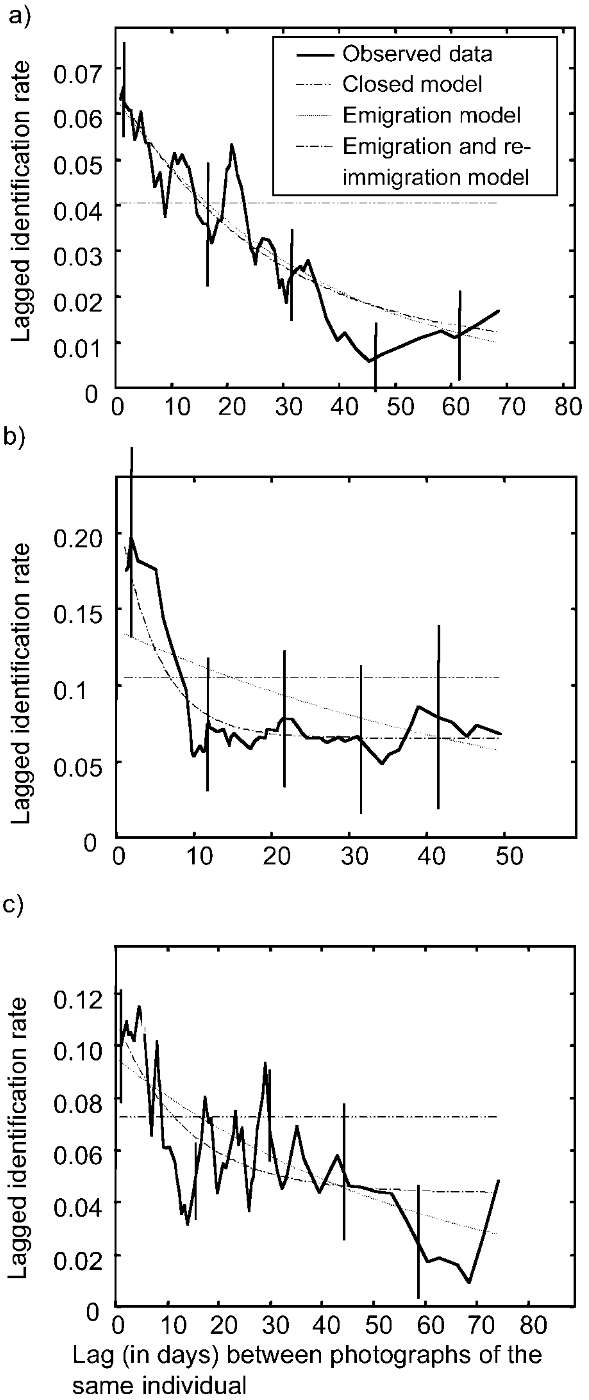

Fig. 5. Lagged identification rate (probability of re-identifying animal after a certain time lag) of northern bottlenose whales in the Gully for each age/sex class: (a) female/immature male; (b) sub-adult male; (c) mature male. Vertical lines are jack-knife error bars.

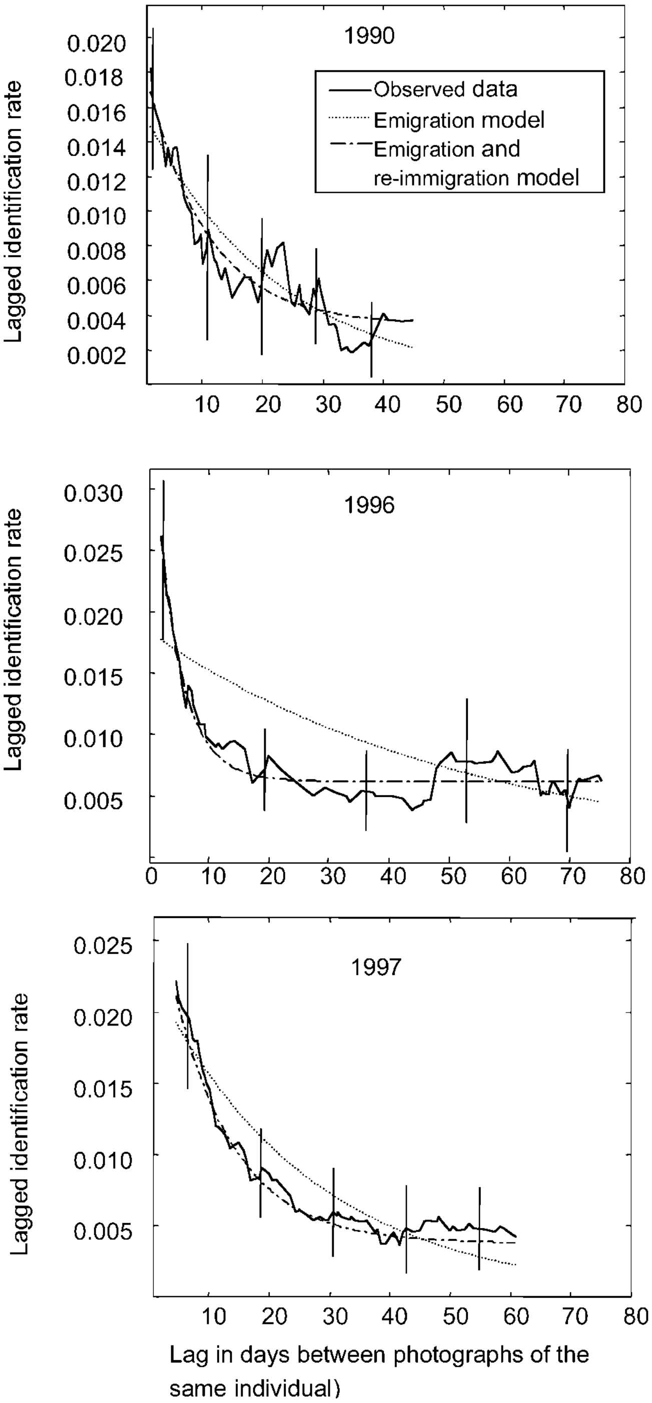

Fig. 6. Lagged identification rate (probability of re-identifying animal after a certain time lag) of northern bottlenose whales in the Gully for each field season that extended over two months. Vertical lines are jack-knife error bars.

estimates of time spent in and out of the Gully by each age/sex class were large (Table 6), so it was difficult to determine whether the different classes have differing residency times in the Gully.

Year differences

Although there were some differences in the residency rate of different age and sex classes (Table 6), all classes were pooled together to increase sample sizes for looking at yearly differences (Fig. 6). Residency rates were calculated for 1990, 1996 and 1997 (all years with more than two months in the field and reasonably large sample sizes). The lagged identification rates for 1990 and 1997 were similar and best fit the emigration and re-immigration model (Table 7). The field season in 1990 was shorter than in 1996 and 1997, which may account for the reduced maximum lag values. In 1990 and 1997, individuals spent 12 days on average in the Gully. In 1996 however, individuals spent fewer days in the Gully (mean = 5 days).

DISCUSSION

Population size and trends

A previous estimate of the Gully population size (230 animals; Whitehead *et al.*, 1997b) was much larger than found in this study (130 animals). However this difference was not due to a declining population, but to a difference in

Table 7

Estimated residency model parameters (±SE) for individuals based on left fin identifications in each of the years with long field seasons (Q≥4). Best-fit models based on Akaike Information Criterion (AIC) are given in *italics*.

Year	Model	Estimated number of individuals in Gully at given time	Mean number of days whales remain in the Gully	Mean number of days whales remain outside of the Gully	AIC
1990 (*n*=119)	Closed	124±21	-	-	2,018
	Emigration	63±17	22±8	-	1,975
	Emigration and re-immigration	*53±19*	*12±12*	*55**	*1,974*
1996 (*n*=81)	Closed	95±20	-	-	1,131
	Emigration	54±16	53±30	-	1,110
	Emigration and re-immigration	*27±9*	*5±3*	*25±17*	*1,096*
1997 (*n*=79)	Closed	103±21	-	-	858
	Emigration	43±11	26±8	-	823
	Emigration and re-immigration	*32±16*	*12±10*	*84±136*	*822*

* SE very large (over 1 million).

the estimated proportion of the population that was reliably marked. In the earlier estimate, only individuals with notches on the dorsal fin were included in the population estimate analysis, and it was estimated that 29% of the population was notched. The estimated number of notched individuals (based on mark-recapture modelling) was similar to the estimated number of reliably marked individuals in this study. However, quantitative analysis of mark change (Gowans and Whitehead, 2001) indicated that 66% of the population can be considered reliably marked. Thus, the difference between the previous estimates of the proportion of notched individuals (29%) and the current estimated proportion of reliably marked individuals (66%) accounted for most of the difference in estimated total population size. The recent analysis of reliable markings was more rigorous than that used by Whitehead *et al.* (1997b) and therefore the new population estimate is more accurate.

The Gully population is small and may be largely distinct from other populations of northern bottlenose whales in the North Atlantic. Differences in sizes of individual whales found in the Gully and those found elsewhere in the North Atlantic (Whitehead *et al.*, 1997b) suggest that this population may be reproductively isolated. The small population size found here also suggests that the Gully population may be relatively isolated; if whales from the Gully were freely mixing with other North Atlantic bottlenose whales, our estimate of 130 animals would apply to the entire North Atlantic. Recent sightings of northern bottlenose whales off Labrador, Iceland and the Faroe Islands indicate that the North Atlantic population is much larger than 130 animals (Gunnlaugsson and Sigurjønsson, 1990; Reeves *et al.*, 1993). Furthermore, there is a statistically significant difference between the distribution of mtDNA haplotypes between the Gully and Labrador (M.L. Dalebout, pers. comm.). The Gully population has probably always been small, although it may still be recovering from the whaling catch of up to 87 individuals between 1962 and 1967 (Reeves *et al.*, 1993). While no significant trend in population size was detected when the mortality + trend model was fitted (Table 3), the size of this small population should continue to be monitored as a larger sample size may indicate a significant trend.

Estimated mortality rates (which also included mark change and permanent immigration) were imprecise (see 95% CI in Table 3) and were higher than expected for a long-lived marine mammal (e.g. Small and DeMaster, 1995). The rate at which individuals gain reliable marks was estimated to be 3.3% per year and such marks were not lost over time (Gowans and Whitehead, 2001), although some marks may be obscured by the gain of new ones. If mark change is estimated at 3% per individual per year, then the mortality + permanent emigration rate can be estimated at 10 or 11% per year for left and right identifications respectively. This is still higher than those found by Small and DeMaster (1995) for other long-lived marine mammals. There are few indications of causes of mortality for the Gully population. However, in August 1999, one immature individual was observed entangled, almost certainly fatally, in monofilament fishing line, probably from the longlines that are set for swordfish (*Xiphius gladius*) across the Gully in late summer and autumn.

Small population sizes and high mortality rates are implicated in the decline and likely extinction of certain cetacean species and populations (e.g. North Atlantic right whales, *Eubalaena glacialis* and vaquita, *Phocoena sinus*; Caswell *et al.*, 1999; Jarmillo-Legorreta *et al.*, 1999). The small size of the Gully population of northern bottlenose whales does not indicate that bottlenose whales are likely to become extinct as recent surveys off Iceland and the Faroe Islands, as well as sightings from the Davis Strait, indicate that northern bottlenose whales are routinely sighted further north than the Gully (Sigurjønsson *et al.*, 1989; Gunnlaugsson and Sigurjønsson, 1990; Reeves *et al.*, 1993). However, little is known about the size of the more northern aggregations. While there is some evidence for reproductive isolation between northern bottlenose whales in the Gully and other areas of the North Atlantic (see above), low levels of migration (one or two individuals per generation) can reduce inbreeding (Stacey *et al.*, 1997) and low levels of migration may be occurring. However, the small population size in the Gully does indicate that the population could easily be threatened by human activity.

Residency rate

Throughout the summer field season, individuals enter the Gully, spend on average approximately 20 days there and then leave, to re-enter at some later time. The inter-annual variability in the use of the Gully (by both proportion of individuals found in the Gully and residency period) could be linked to either ecological factors or human activity. Annual patterns of distribution and abundance of northern bottlenose whales in the Gully were correlated with some oceanographic features (e.g. depth of scattering layer; Hooker, 1999). However changes in ecological factors between 1990, 1996 and 1997 (such as prey density or distributions) have not been directly studied (e.g. Harrison and Fenton, 1998 and references therein). There have been marked differences in human activity near the Gully over this time period. In 1990, there was an active fishery for groundfish along the edges of the Gully and little activity related to natural gas exploration or exploitation. However, in 1996 and 1997 there was no groundfish fishery in the area (due to a moratorium imposed in 1993) but there was an increase in activities related to gas exploration and exploitation.

CONCLUSION

Results from this study indicate that the Gully population of bottlenose whales is smaller than previously estimated, although a declining population is not indicated. Analysis of the residency patterns of individuals in the Gully indicates that individuals routinely visit the Gully (likely several times a year) for days to months at a time, and thus the Gully area appears to be an important habitat for these whales. Establishment of a marine protected area, which prohibits the activities that threaten these whales, is an excellent way of ensuring the survival of this unique population. However, since individuals appear to leave the Gully regularly, it is suggests that protection in the Gully alone may not be sufficient. Further work is needed to assess the importance of other potential habitats along the shelf edge and deeper offshore waters.

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[*Appendix 1 is overleaf*]

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Appendix 1

POPULATION ESTIMATION MODELS

Beginning with the closed (Schnabel) model, let N be the population size. There are I samples, $i = 1,...,I$ at times $t_1,...,t_I$, and on the ith sample n_i individuals are identified. Then the identification rate on the ith sample is:

$$p_i = n_i / N \tag{1}$$

The probability that an animal sighted on the ith sample is next sighted on the jth sample is:

$$q_{ij} = p_j \prod_{k:i<k<j} (1-p_k) \tag{2}$$

And the probability that an animal sighted on the ith sample is not sighted again is:

$$r_i = \prod_{k:i<j\leq I} (1-p_j) \tag{3}$$

If, of the n_i individuals identified on the ith sample, m_{ij} are next sighted on the jth sample, and s_i are not sighted again, then the log-likelihood of the dataset (conditioning on first capture) is approximately:

$$L = \sum_{i:i=1,...I-1} [\sum_{j:j=i+1,...I} m_{ij} Log(q_{ij})] + s_i Log(r_i) \tag{4}$$

N is simply chosen to maximise L in equation (4) using the Nelder-Mead Simplex method.

For the mortality model (with mortality plus emigration plus mark change of delta (δ) per animal per year), equations (2) and (3) are changed by:

$$q_{ij} = e^{-\delta(t(j)-t(i))} p_j \prod_{k:i<k<j} (1-p_k) \text{, and} \tag{5}$$

$$r_i = \prod_{j:i<j\leq I} [e^{-\delta(t(j-1)-t(i))} (1 - e^{-\delta(t(j)-(t(j-1)))}) \prod_{k:i<k<j} (1-p_k)] + e^{-\delta(t(I)-t(i))} \prod_{k:i<k\leq I} (1-p_k) \tag{6}$$

Now we choose both N and δ to maximise L in equation (4).

Finally, for the mortality plus trend model, with a rate of growth of the population at mu (μ) per year, equation (1) is changed by:

$$p_i = n_i / (N_M e^{\mu(t(i)-0.5(t(I)-t(1)))}) \tag{7}$$

where N_M is the population size at the midpoint of the sampling, $0.5(t(I)\text{-}t(1))$

Now we choose both N_M, μ and δ to maximise L in equation (4).

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Osteological variation in the spectacled porpoise (*Phocoena dioptrica*)

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ABSTRACT

Cranial and post-cranial variation is described for a large series of specimens of spectacled porpoise from Argentina and compared with that for specimens from other areas of the Southern Hemisphere. Condylobasal length in 54 adult skulls was 276-424. Tooth counts were 16-26 and 17-23 in the upper and lower jaws, respectively. Total number of vertebrae ($n = 20$) was 66-70. The rostrum may be relatively smaller in the Auckland Islands than in other regions.

KEYWORDS: SPECTACLED PORPOISE; SOUTHERN HEMISPHERE; MORPHOMETRICS; STOCK IDENTITY

INTRODUCTION

Before Goodall began her systematic collections of beached remains of marine mammals along the southern coasts of Argentina and Chile in the mid-1970s (Goodall, 1978), there was little available information on the spectacled porpoise (*Phocoena dioptrica*). Only a handful of specimens existed in the world's museums, and even fewer had been documented in the literature. Brownell (1975) summarised knowledge of the species, including osteological data reported by Lahille (1912), Marelli (1922), Hamilton (1941) and Praderi (1971). Data on additional specimens have been reported subsequently by Baker (1977), Goodall (1978), Goodall and Cameron (1979), Guiler *et al.* (1987, as *Phocoena spinipinnis*, see Brownell, R.L. *et al.*, 1989), Goodall and Schiavini (1995) and Brownell and Clapham (1999). The skull was illustrated by Brownell (1975), Goodall (1978) and Brownell and Clapham (1999) and the post-cranial skeleton by Brownell (1975) and (in part) Goodall and Cameron (1979). Much more material is now available, and the purpose of this paper is to describe individual and geographic variation in the skull and post-cranial skeleton based on the larger series of specimens.

MATERIALS AND METHODS

The new sample consisted of 111 osteological specimens, ranging from only a few isolated bones (e.g. the fused cervical vertebrae) to complete skeletons with data on sex and length, all from southern Argentina (Appendix 1).

A major problem was how to decide which specimens to include in the 'adult' series for cranial measurements. Very small skulls with obvious juvenile characteristics (e.g. unankylosed maxillae, frontals and other major elements) were easily identified as non-adults. However, no characteristics that clearly and consistently separated sub-adults from adults were found. The specimens were therefore allocated to 'adult' and 'non-adult' series based on condylobasal (CB) length and the few available data on sexual and physical maturity. Perrin and Heyning (1993) noted that cranial maturity (cessation of elongation of the skull) is attained in at least some small odontocetes at approximately the time of sexual maturation and before the onset of physical maturity (cessation of increase in body length, signalled by fusion of all vertebral epiphyses to the centra). Data on sexual maturity existed for four specimens (two males and two females) and on physical maturity for 27 specimens ranging from 262-324mm in CB length. A male of CB length 276mm was physically mature. A female of CB length 279mm was both physically and sexually immature. The male was included in the adult series and the female and three physically immature specimens (with no information on sexual maturity, and with CB lengths of 262, 275 and 276mm) were excluded. Also excluded were skulls for specimens known to be sexually immature or of unknown maturity for which it was not possible to determine CB length because of damage to the tip of the rostrum. These criteria were used to minimise the inclusion of relatively large but immature skulls and the exclusion of relatively small but mature skulls; the adult sample for CB length included 54 specimens.

For post-cranial measurements, specimens known to be physically mature (vertebral epiphyses fused to centra) were included. This yielded a series of 22 specimens.

Measurements were taken after Perrin (1975). Most of the cranial measurements were taken by Perrin (46 specimens), with some by Cozzuol (8) and one skull measured by Alejandro Purgue (pers. comm.). The post-cranial measurements were made by Perrin (10), Purgue (9) and Cozzuol (3). Measurement technique was standardised among Perrin, Cozzuol and Purgue by inter-comparison of measurements and re-measurements of a series of specimens at the beginning of the study. CB length for one previously unpublished adult specimen was contributed by R. Praderi (pers. comm.).

Published meristic data (tooth counts and post-cranial vertebral and rib counts) were included in the sample for statistical analysis, but published cranial measurements were not, because of the potential for differences in measurement technique.

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Table 1

Statistics for cranial measurements of adult specimens of *Phocoena dioptrica* in present sample, in mm.

	Range	(*n*)	Mean	SD	CV
Condylobasal length	276-324	(54)	297.3	10.96	3.68
Rostrum					
Length	112-139	(42)	123.1	6.33	5.15
Width at base	71-92	(46)	81.8	4.38	5.35
Width at ¼ length	55-73	(50)	64.1	3.74	5.83
Width at ½ length	45-61	(47)	53.0	3.59	6.78
Width at ¾ length	36-48	(44)	40.6	3.27	8.05
PMX width at ½ length	21-37	(48)	27.3	3.06	11.30
Tip of rostrum to:					
External nares	133-176	(53)	158.5	8.71	5.49
Internal nares	151-190	(49)	166.9	8.72	5.23
Preorbital width	132-167	(45)	151.3	7.87	5.20
Postorbital width	160-188	(50)	172.9	6.84	3.96
Zygomatic width	161-190	(44)	175.8	7.41	4.21
Width of external nares	26-42	(54)	33.9	3.01	8.88
Max. width of PMXs	39-54	(53)	46.4	3.45	7.44
Parietal width	128-158	(51)	141.1	6.63	4.70
Height of braincase	90-115	(53)	101.9	5.48	5.38
Int. length of braincase	101-124	(54)	111.7	5.67	5.08
Length of temporal fossa	44-73	(50)	58.4	6.21	10.63
Height of temporal fossa	32-65	(50)	45.0	6.33	14.07
Length of orbit	47-34	(51)	55.5	3.41	6.14
Length of antorb. process	20-34	(49)	27.6	3.47	6.25
Width of internal nares	53-66	(41)	59.6	3.30	5.54
Separation of pterygoids	5-26	(22)	15.9	-	-
Length of upp. toothrow	85-111	(22)	97.3	-	-
Length of low. toothrow	75-108	(16)	91.8	-	-
Length of ramus	203-229	(18)	218.7	-	-
Height of ramus	58-68	(18)	63.9	-	-
Max. diameter of tooth	1.6-4.0	(17)	2.55	-	-

Table 2

Coefficients of variation for cranial measurements of (A) *Phocoena dioptrica* from Argentina (from Table 1), *Phocoena phocoena* from the (B) eastern North Atlantic and (C) western North Pacific (Amano and Miyazaki, 1992; sample sizes 29-39), and (D) offshore specimens of *Stenella attenuata* from the eastern tropical Pacific (Perrin, 1975; sample sizes 65-70).

	A	B	C	D
Condylobasal length	3.68	5.02	5.02	3.14
Rostrum:				
Length	5.15	6.40	6.81	4.17**
Width at base	5.35	8.39	7.22	4.34**
Width at ¼ length	5.83	9.81	7.76	-
Width at ½ length	6.78	9.98	6.98	6.96**
Width at ¾ length	8.05	9.61	7.46	9.33**
PMX width at ½ length	11.30	12.44	9.78	10.14**
Tip of rostrum to:				
External nares	5.49	6.51	7.03	4.39**
Internal nares	5.23	-	-	4.24**
Preorbital width	5.20	8.19	6.39	3.56**
Postorbital width	3.96	6.29	5.69	3.02**
Zygomatic width	4.21	6.56	5.87	3.18**
Width of external nares	8.88	8.66	8.48	4.96
Max. width of PMXs	7.44	-	-	4.38**
Parietal width	4.70	4.08	3.73	3.40**
Height of braincase	5.38	-	-	4.37**
Int. length of braincase	5.08	-	-	-*
Length of temporal fossa	10.63	7.62	9.19	6.27**
Height of temporal fossa	14.07	12.08	13.51	6.31**
Length of orbit	6.14	-	-	4.26
Length of antorb. process	6.25	-	-	6.69**
Width of internal nares	5.54	8.71	6.90	7.20**

*Measurement determined to be sexually dimorphic in *S. attenuata* by Perrin (1975). ** Subsequently determined by Schnell *et al.* (1985) to be sexually dimorphic in *S. attenuata*.

RESULTS AND DISCUSSION

The skull

Fifty-four skulls ranged from 276-324mm in CB length (Table 1). Cranial variability was less than in comparable series of specimens of the harbour porpoise (*Phocoena phocoena*) from the eastern North Atlantic and western North Pacific, but greater for most dimensions than in a series of offshore specimens of the pantropical spotted dolphin (*Stenella attenuata*) from the eastern tropical Pacific (Table 2). The latter difference is most pronounced for width of the skull and of length and height of the temporal fossa. As the specimens for the most part were not identified to sex, an unknown proportion of this variability may be due to sexual dimorphism. The lesser variability of this pelagic species compared to that of the more coastal harbour porpoise may suggest less populational sub-division because of greater individual home range or greater genetic flow across the species range within an oceanic region. Other possible factors to consider in these comparisons are population size and age, both known to correlate with genetic variability (Nei, 1987). For example, the eastern tropical pelagic populations of *Stenella* spp. are thought to possibly be of relatively recent origin (Perrin *et al.*, 1985; 1991) and thus, other factors being equal, could perhaps be expected to exhibit less genetic (and potentially phenotypic) variability than older populations of pelagic small cetaceans. Selection is another potential factor. Lesser phenotypic variability may reflect an adaptive premium on more standardised size or shape.

Table 3

Statistics for tooth/alveolus counts and postcranial meristic characters in *Phocoena dioptrica.* Includes present sample and data from Lahille (1912), Marelli (1922), Hamilton (1941), Praderi (1971) and Baker (1977). Standard deviations (SD) and coefficients of variation (CV) included for samples of 25 or more.

	Range	(*n*)	Mean	SD	CV
Tooth/alveolus counts:					
Upper left	16-25	(22)	20.5	-	-
Upper right	18-24	(22)	20.5	-	-
Lower left	17-23	(23)	18.9	-	-
Lower right	17-23	(22)	18.5	-	-
Vertebrae:					
Total number	66-70	(20)	67.3	-	-
Thoracic	13-14	(40)	13.7	0.45	0.33
Lumbar	13-16	(30)	13.6	1.04	7.64
Caudal	29-34	(14)	32.1	-	-
First with vert. for.	40-46	(30)	43.7	1.62	3.71
Last with trans. proc.	44-48	(30)	45.5	1.11	2.44
Last with neur. proc.	50-53	(30)	51.5	1.14	2.21
First with chevron	35-36	(7)	35.7	-	-
Fused cervicals	5-7	(63)	5.7	0.56	9.91
Widest vertebra	22-25	(33)	23.2	0.97	4.18
Number of ribs:					
Left vertebral	13-14	(31)	13.7	0.48	3.47
Right vertebral	13-14	(28)	13.6	0.50	3.68
Left sternal	7-9	(14)	7.5	-	-
Right sternal	7-9	(17)	7.5	-	-

Tooth counts ranged from 16-25 in the upper jaw and 17-23 in the lower jaw (Table 3), for ranges of 9 and 6 teeth, respectively. This is comparable to the range of variation found by Amano and Miyazaki (1992) in comparable samples of the harbour porpoise (22-30 upper and 21-30 lower, for ranges of 8 and 9 teeth), as well as in the earlier study by Yurick and Gaskin (1987; 21-29 upper and 20-29 lower). However, the lower end of the ranges in the spectacled porpoise may reflect missing teeth (from ill-defined or abraded alveoli). The teeth are usually spatulate but can also be peg-like with minimally expanded cusps (Fig. 1). Some of the teeth may be apically flattened due to wear.

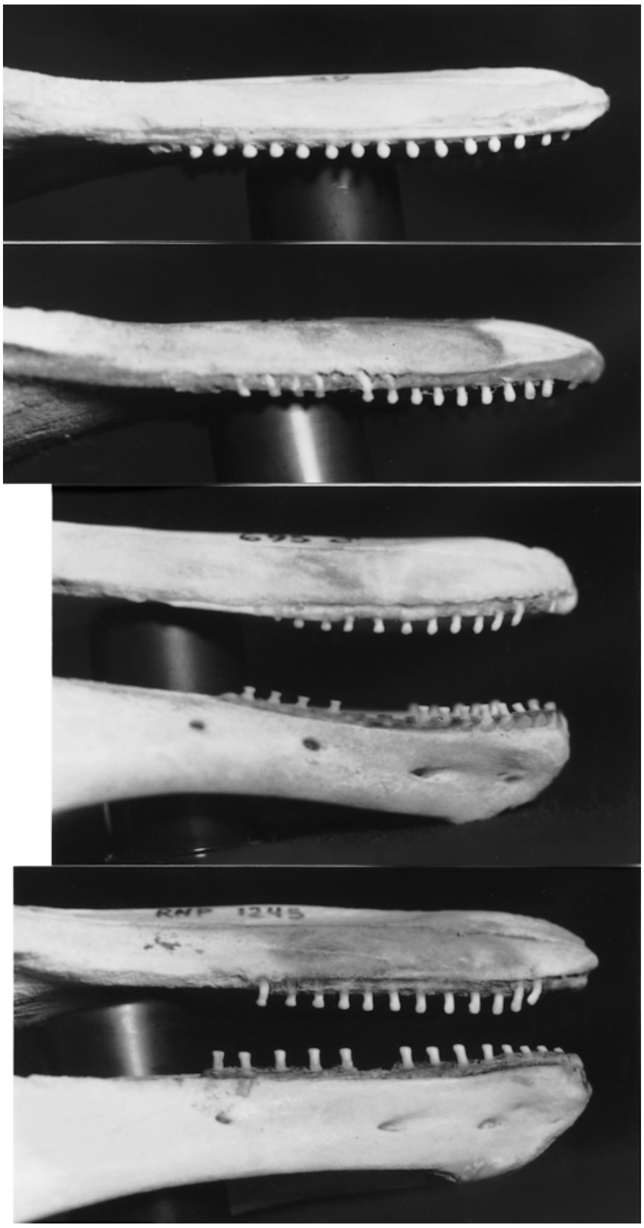

Fig. 1. Variation in tooth shape in *Phocoena dioptrica*: (top to bottom) RNP 39, RNP 1965, RNP 695 (male), RNP 1245, all from Tierra del Fuego.

The post-cranial skeleton

Although the present sample is small (20), the variation in total vertebral count (66-70) is comparable to that reported for regional series of other delphinoids, e.g. 67-72 (CV = 1.5) in 52 specimens of Atlantic spotted dolphin (*Stenella frontalis*) from the Atlantic (Perrin *et al.*, 1987), 77-83 (CV = 1.6) in 51 pantropical spotted dolphin specimens from the eastern tropical Pacific (Perrin, 1975), and 74-80 (CV = 2.0) in 80 short-beaked common dolphin specimens (*Delphinus delphis*) from southern California (Heyning and Perrin, 1994). It is lower than for the pantropical spotted dolphin worldwide (74-84 in 175 specimens, CV = 1.9; Perrin *et al.*, 1987). The greatest variation is in the number of caudals (29-34 in 14 specimens). The typical vertebral formula is C7+T14+L14+Ca32 = 67. The position of the last vertebra bearing a transverse process (44-48) and the last bearing a neural process (50-53) are very stable (CV = 2.44 and 2.21, respectively). The number of fused cervicals ranges from 5 to 7 and is highly variable (3-7, CV = 13.04).). Statistics for postcranial measurements of physically mature specimens of *Phocoena dioptrica* in the present sample are shown in Table 4.

Table 4

Statistics for postcranial measurements of physically mature specimens of *Phocoena dioptrica* in present sample, in mm (except total length of skeleton, which is in cm).

	Range	(*n*)	Mean
Atlas:			
Width of anterior face	66-83	(15)	77.1
Height	44-58	(15)	53.3
Length of lateral process	18-39	(16)	29.1
Length of neural spine	15-50	(15)	39.1
First thoracic vertebra:			
Height	54-67	(17)	60.4
Maximum width	72-96	(17)	84.7
Length of neural spine	13-46	(13)	35.6
First lumbar vertebra:			
Height	57-74	(14)	64.7
Maximum width	181-208	(12)	191.5
Length of neural spine	71-94	(11)	85.7
Length of first vertebral rib	135-168	(13)	152.5
Length of longest vertebral rib	296-341	(9)	319.1
Maximum width of manubrium	87-111	(8)	95.9
Greatest length of radius	-	(1)	70
Greatest length of ulna	-	(1)	63
Maximum width of humerus	-	(1)	35
Length of longest chevron	40-56	(7)	48.1
Greatest length of pelvic	62-107	(3)	85.0
Width of widest vertebra	186-221	(14)	200.4
Length of centrum of first lumbar	31-36	(14)	33.3
Total length of skeleton (cm)	169-205	(5)	183.8

Comparison with previously published data

The published measurements for Argentine specimens (Table 5) fall within the ranges for the present sample with a few exceptions. Marelli (1922) reported basal width of the rostrum for his specimen as 129mm, considerably above the range for all other specimens in Tables 1 and 5. His photographs of the specimen do not show it to be markedly different in form from those examined by us, and the difference must be ascribed to measurement error or to a measuring method different from that used by others.

Praderi (1971) reported basal width and half-length width of the rostrum for one of his specimens as 97mm and 62mm, respectively, slightly above the range for the present sample. Another had a rostrum length slightly below the range for the present sample, and a third had maximum skull height also slightly below the range. These small differences can be ascribed to slight differences in measuring technique.

Geographical variation

Marked differences in skull measurements have been found for the closely related harbour porpoise between ocean basins and even between opposite sides of the North Atlantic (Yurick and Gaskin, 1987; Amano and Miyazaki, 1992), and it would not be surprising to find such variation within the broad range of *P. dioptrica*. The sample sizes are very small for other than southern Argentina, but some patterns are suggested.

Table 5

Published cranial measurements (in mm) of adult specimens of *Phocoena dioptrica* from Argentina (A, Marelli, 1922; B, Praderi, 1971, sample size four unless otherwise noted), Falkland Islands/Islas Malvinas (C, Hamilton, 1941), Enderby Island in Auckland Islands (D, Baker, 1977) and Heard Island (E, Guiler, 1987).

	A	B	C	D	E
Condylobasal length	315	285-295	288	310	303
Rostrum:					
Length	-	110-125	121	117	162*
Width at base	129*	79-97	88	84	82
Width at ½ length	57	54-62	-	51	51
Width at ¾ length	-	-	-	38	38
PMX width at ½ length	-	-	32	29	31
Preorbital width	-	-	155	162	164
Postorbital width	153	-	170	-	-
Zygomatic width	-	153-171	168	-	169
Max. width of PMXs	-	45-52(3)	45	45**	-
Parietal width	-	-	143	157	156
Length of temporal fossa	-	42-48	-	61	42
Height of temporal fossa	-	34-36	-	58	39
Length of upp. toothrow	92	84-95	-	81	79
Length of low. toothrow	-	82-96	-	-	-
Length of ramus	-	213-225(3)	-	-	-
Height of ramus	-	59-60(2)	-	-	-
Max. diameter of tooth	-	-	-	3.0	-
Max. height of cranium	-	132-144(3)	-	155	163

* Erroneous values (see text).

** Corrected from value of 78mm in Baker (1977).

The Falklands/Malvinas specimen falls within the range for the mainland Argentine series in all measurements. Guiler *et al.* (1987) reported length of the rostrum for the Heard Island specimen as 162mm, far above that reported for any other specimen. This is an error; measurement of the rostrum in the published photograph of the skull yields a value of approximately 123mm, within the range for other specimens. Tooth counts (14/13) and length of upper tooth row (71/79) are below the ranges for other specimens, but it appears in the photograph that the proximal portion of the rostrum was severely abraded latero-ventrally, obliterating the posterior ends of the rows of alveoli and yielding artificially low alveolus counts and tooth row lengths.

The Auckland Islands specimen appears to differ significantly from the other series in two features. The rostrum is relatively very small (117mm vs CB length of 310mm, for a ratio of 0.377, as opposed to a range of 0.381-0.443 and an average of 0.413 in the 52 adult Argentine skulls in the present sample). The length of the upper tooth row (81mm) falls below the range of 85-111mm in the Argentine sample of 28 (Tables 1 and 5). It is possible that this reflects a smaller rostrum size in the Auckland Islands population than in the others.

Larger samples from throughout the range of the species will be necessary to allow confirmation of the geographical patterns of variation suggested by the present material.

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APPENDIX 1

SPECIMENS OF *PHOCOENA DIOPTRICA* EXAMINED

Centro Nacional Patagónico, Puerto Madryn, Chubut, Argentina (CNP) 116; Instituto Tecnológico de Estudios Superiores de Monterey, Guaymas, Mexico RNP 429, 757; Instituto de Zoología, Universidad Austral, Valdivia, Chile (IZUA) RNP 65; Los Angeles County Museum (LACM) 86042 (RNP 1146), 86043 (RNP 583); Museo Acatushún de Aves y Mamíferos Australes, Harberton, Tierra del Fuego, Argentina RNP 10, 18, 33, 38, 39, 41, 46, 71, 82, 83, 85, 98, 99, 123, 125a, 131, 146, 174, 194, 195, 205, 221, 232, 234, 267, 268, 281, 292, 297, 299, 301, 318, 324, 363, 364, 376, 401, 412, 431, 438, 440, 443, 448, 449, 454, 455, 460, 463, 464, 469, 494, 505, 533, 536, 589, 600, 609, 621, 625, 658, 690, 694, 695, 737, 750, 759, 770, 776, 870, 896, 906, 969, 1000, 1008, 1013, 1014, 1018, 1084, 1095, 1196, 1220, 1245, 1313, 1333, 1348, 1353, 1461, 1465, 1481, 1547, 1615, 1622; Museo Nacional de Historia Natural de Montevideo (MNHN-M) RNP 525; Museo de La Plata (MLP) 1201, 1202; Museo Argentino de Ciencias Naturales Bernardino Rivadavia (MACN) 20491 (RNP 525), 20492 (RNP 732), 20493 (RNP 298), Ad-1; Museum of New Zealand Te Papa Tongarewa (MNZ) 1977 (RNP 970), 1978 (RNP 599); Southwest Fisheries Science Center (SWFC) 0122 (RNP 319); US National Museum of Natural History (USNM) 571485, 571486, 571487 (RNP 36, 1030, 1061).

First report of a common dolphin (*Delphinus delphis*) death following penetration of a biopsy dart

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ABSTRACT

The remote collection of skin and blubber biopsy samples from free-ranging cetaceans is a powerful technique which has been increasingly used by scientists in recent years in a wide range of applications, particularly with respect to genetic and contaminant studies. Biopsy sampling, if carried out responsibly, is known to cause low-level reactions, and is unlikely to produce long-term deleterious effects. However, this technique is not completely devoid of risk for the sampled animals, particularly for smaller odontocetes. This paper reports the death of a common dolphin in the central Mediterranean Sea, following penetration of a biopsy dart and subsequent handling. The dolphin was hit in the dorsal muscle mass below the dorsal fin by a lightweight pneumatic dart fired from a distance of 6m by a variable-power CO_2 dart projector. The methods and equipment had been previously successfully used with minimal effect on common dolphins and other species under similar conditions; it was therefore considered to be relatively uninvasive and more likely to reduce disturbance while increasing sample retrieval. However, in the reported event, a dart stuck in the dorsal muscle mass instead of recoiling as expected. Less than 2min after the hit, the dolphin began catatonic head-up sinking, and was recovered by a team member at depth. Basic medical care was given to ensure haemostasis, but the animal died 16min later. Minimal overall bleeding and a small wound in the thick muscle mass were not among the suspected causes of death. This may have been the consequence of either indirect vertebral trauma or stress. Furthermore, the dolphin had a relatively thin (7mm) blubber layer, that may have contributed to the unwanted outcome of the biopsy attempt. The author stresses that scientists should only adopt even mildly intrusive research methods after careful review and risk assessment in the light of the precautionary principle, and that their decisions must be reviewed on a regular basis according to the best available evidence.

KEYWORDS: BIOPSY SAMPLING; TECHNIQUES; COMMON DOLPHIN; MORTALITY; STRESS; MEDITERRANEAN

INTRODUCTION

The remote collection of skin and blubber biopsy samples from free-ranging cetaceans is a powerful technique which has been commonly used by scientists in recent years. It involves a minimal level of intrusiveness and analyses of the resulting samples can address many questions that previously could only be answered using samples collected from dead animals (e.g. see IWC, 1991; Aguilar and Borrell, 1994b; Lambertsen *et al.*, 1994; Barrett-Lennard *et al.*, 1996; Weller *et al.*, 1997). For example, genetic analyses of skin samples can provide information on *inter alia* social organisation, kinship, mating system, individual gender and identification, movement patterns, population size, stock identity, genetic phylopatry and variability within and among populations (e.g. Amos and Hoelzel, 1990; Palsbøll *et al.*, 1992; Baker, C.S. *et al.*, 1993; Bérubé *et al.*, 1998; Palsbøll, 1999). Analysis of the blubber portion of the samples can be used to determine contaminant levels (e.g. Aguilar and Borrell, 1994a), for various biomarker analyses and toxicological tests performed on cell cultures (e.g. Fossi *et al.*, 1992; 2000; Marsili *et al.*, 1998), and for gaining information on feeding ecology and nutritive condition through the examination of stable isotopes, fatty acids and lipid content in the blubber (e.g. Aguilar *et al.*, 1992; Kakela and Hyvarinen, 1998; Walker *et al.*, 1999; Das *et al.*, 2000).

Many authors have suggested that biopsy sampling, if carried out responsibly, is likely to cause only low-level and short-term reactions (e.g. Aguilar and Nadal, 1984 on striped dolphins, *Stenella coeruleoalba*; Cockcroft, 1994; Weller *et al.*, 1997 on bottlenose dolphins, *Tursiops truncatus*; Barrett-Lennard *et al.*, 1996 on killer whales, *Orcinus orca*; Weinrich *et al.*, 1992; Clapham and Mattila, 1993 on humpback whales, *Megaptera novaeangliae*; Jahoda *et al.*, 1996 on fin whales, *Balaenoptera physalus*; Gauthier and Sears, 1999 on various cetacean species and see the review in IWC, 1991) and is not likely to produce any long-term deleterious effects. However, it must be remembered that biopsy sampling – as any 'intrusive' research approach – will entail some level of risk, however small. For example, most biopsy sampling studies involve some level of disturbance to the animals, and a variable occurrence of 'undesired' events. These may include missed shots, stuck darts or broken tips remaining attached to the animals, snagging of the dart retrieval line on the animal's flukes, repeated sampling of one individual, etc. (e.g. Aguilar and Nadal, 1984; Brown, M.W. *et al.*, 1991; Weinrich *et al.*, 1992; Clapham and Mattila, 1993; Brown, M.R. *et al.*, 1994; Patenaude and White, 1995; Barrett-Lennard *et al.*, 1996; Gauthier and Sears, 1999). Most studies report a minority of 'strong' or 'excited' short-term reactions by the animals, which are generally considered to have no 'long-term effect' on the animals' welfare (e.g. IWC, 1991; Aguilar and Borrell, 1994b).

The published literature does not provide accounts of remote biopsy sampling attempts having fatal consequences for any cetacean species, despite the many thousands of biopsy samples taken. More specifically, 76 common dolphin biopsies were collected with a spear gun off northwest Spain and in the Gibraltar Strait without observed fatalities (Borrell *et al.*, 1998; In press). This paper reports the death of a common dolphin (*Delphinus delphis*) following penetration of a biopsy dart and subsequent handling, during a biopsy darting attempt in the central Mediterranean Sea[1]. It is hoped that making this information fully available to the wider research community will

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[1] As a consequence of this event, the Tethys Research Institute has immediately interrupted its ongoing biopsy sampling activities. Subsequently, a substantial re-consideration of Tethys biopsy-related policy on the basis of the new evidence has resulted in guidelines that include abandoning biopsy darting on small cetaceans.

encourage a careful evaluation of the risks related to biopsy sampling methods, particularly as far as biopsy darting on small cetaceans is concerned.

THE COMMON DOLPHIN INCIDENT

Experience of research team

Previous experience of biopsy sampling gathered by the Tethys Research Institute over the last decade includes the remote collection of 457 samples from free-ranging cetaceans, including Mediterranean fin whales (*Balaenoptera physalus*, $n = 196$), sperm whales ($n = 4$), long-finned pilot whales (*Globicephala melas*, $n = 1$), Risso's dolphins (*Grampus griseus*, $n = 26$), bottlenose dolphins ($n = 12$, including six biopsy samples taken with a CO_2 rifle, two with a hand crossbow and one with a biopsy pole), striped dolphins ($n = 202$, including 88 biopsy samples taken with a biopsy pole and 114 samples of epidermal skin cells swabbed with a scratching tissue mounted on top of a biopsy pole), and common dolphins ($n = 16$, including seven biopsy samples taken with a CO_2 rifle, seven with a hand crossbow and two with a biopsy pole). The biopsy tips always consisted of hollow stainless steel cylinders of various measures, according to the size of the target species. The hollow cylinder, threaded at its end, included either a hooked retention needle or a barbed dental broach. A stopper on the rear portion of the biopsy cylinder was used to control penetration to a maximum depth and cause the dart to recoil once the sample was taken. The sterilised biopsy tip was routinely disinfected prior to any biopsy attempt.

Biopsy attempts normally resulted in absent to moderate behavioural reactions elicited in the sampled animal or in the group (e.g. Jahoda *et al.*, 1996). For common dolphins, only minimal short-term reactions by the animals were recorded after a biopsy sample was obtained (Therkildsen, 2000). Typically, the biopsied animal reacted by making a hard tail flick at the instant of dart impact (Weinrich *et al.*, 1992; Weller *et al.*, 1997), followed by a long dive. Similar short-term startle reactions were observed when the dart hit the water near the dolphin (Therkildsen, 2000), suggesting that a large component of any reaction (due to either hit or miss) is a startle response (e.g. see IWC, 1991)[2]. The previous behavioural activity was normally resumed within minutes. The biopsied animal often re-approached the boat after being sampled, and no reactions indicative of severe stress, reduced vitality or harm were recorded. All individual common dolphins that could be photo-identified prior to a biopsy attempt were repeatedly resighted in the same area, as did the other photo-identified group members, with no indications of long-term responses or increased boat avoidance (E. Politi, pers. comm.) The same observations are true of bottlenose dolphins sampled in the same area.

The incident

In June 2000, a biopsy dart aimed at a common dolphin stuck in its muscle mass below the dorsal fin and, although not producing a lethal wound, apparently produced physical and/or physiological consequences that were fatal to the animal (Table 1). The dolphin was swimming in a group including eight other individuals[3], five of which were surrounding the boat in a loose formation at the time of sampling. The event took place in the eastern Ionian Sea

Table 1

Chronological report of the common dolphin death.

Time (min.sec.)	Notes
00’00”	Biopsy dart implant (local time 11:44hrs); the dolphin stops swimming and ‘freezes’, then stays at the surface with no forward movement, the body slightly arched dorsally.
01’00”	The dolphin is staying at the surface, jerks and does not swim; moderate bleeding from the wound; a crew member enters the water and stays besides the boat at about 8m from the dolphin, ready to assist; however, he does not approach to avoid further stress; after a few seconds he comes back on board.
01’15”	The dolphin shows clear signs of distress and stands in a head-up vertical position; the boat approaches at minimum speed, up to about 6m from the animal.
01’50”	The dolphin starts sinking; a crew member enters the water, dives and recovers the animal about 4-5m deep, while it was rapidly sinking in a catatonic vertical position, head up; as soon as he reaches the surface with the dolphin, the crew member extracts the dart and presses his hand on the wound to stop the bleeding; another crew member enters the water and helps to gently bring the dolphin close to the motionless boat; engine turned off; no noises on board; the rest of the dolphin group moves away.
02’13”	The dolphin is held in the water besides the inflatable and sheltered from direct sunlight; two crew members stay in the water and keep the dolphin at the surface with the blowhole out of the water; one crew member keeps pressing his hand on the wound to prevent it from bleeding; the dolphin breaths frequently, at intervals of about 10sec.
04’40”	By taking advantage of the first-aid kit on board, a small cotton ‘cork’ saturated with disinfectant is put on the wound as a haemostatic; a disinfected sterile gauze, kept in place by hand, is also placed on the wound; the dolphin looks quiet and stays motionless, never trying to escape or react to rescue operations; the heart – as perceived by placing a hand on the dolphin chest – beats at a slower rhythm compared to the initial time of handling; whistles and clicks are occasionally emitted; the gauze is kept on the wound to prevent bleeding.
09’30”	Two adults from the dolphin group shortly approach up to about 15m from the boat; whistles emitted by these two dolphins are heard by the crew; the wounded dolphin breaths normally and looks quiet; the heart beat is still relatively slow; the blood on the top of the wound appears to be regularly clotting.
10’48”	The dolphin makes weak movements with the tailstock for a few seconds; the crew considers releasing the animal, but decides to wait a little longer to ensure a lasting haemostasis as the wound still bleeds if the gauze is displaced.
13’00”	The heart starts beating more rapidly.
14’34”	The dolphin vomits a greyish-brown liquid; we notice that respiration may have stopped; desperate attempts to blow air into the blowhole.
15’33”	The dolphin has stopped breathing; the heart continues to beat rapidly.
16’05”	The heart stops beating.

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[2] This is consistent with observations of common and striped dolphins that did not stop bowriding or shortly returned to the vessel after a sample was taken by means of a biopsy pole (Aguilar and Nadal, 1984; IWC, 1991; Tethys Research Institute, unpublished data). This minimal behavioural reaction can be due to the frenzy of the moment, as bowriding animals are in a state of arousal and may be expecting tactile stimuli (Clapham and Mattila, 1993).

[3] Several members of this group were resighted in the study area during the same summer, and showed no sign of boat avoidance.

coastal waters (38°38’09″N, 20°58’22″E), in the context of a longitudinal study on common dolphin and bottlenose dolphin behavioural ecology and ecotoxicology (Politi, 1998; Marsili *et al.*, In press). The crew comprised six people (the author, four experienced research assistants and one volunteer). The research platform was a 4.7m inflatable boat with fiberglass keel, powered by a 50HP, 4-stroke outboard engine.

The dart was fired from a variable-power dart projector (*Pneudart* Model 176B, designed for wildlife injection and marking darts) using 12g *Umarex* CO_2 capsules to pressurise a sealed chamber. The rifle had a knurled knob on the rear of the bolt as a CO_2 pressure control. The dart, stopper and dart tip were identical to those described by Barrett-Lennard *et al.* (1996) for use with killer whales. However, a smaller biopsy tip (20mm long), with a 6mm external and 5mm internal diameter was used in this case. This hollow biopsy tip typically retained a cylindric sample of 5mm diameter[4]. The total weight of an assembled dart was 11.5g. These darts are much smaller than the darts used in other systems, and a minimum of four times lighter, to minimise the energy transferred to the target animal by biopsy strikes (Barrett-Lennard *et al.*, 1996). Our research team believed that for use with bottlenose and common dolphins, lightweight pneumatic darts shot by a variable power rifle may be more appropriate than the crossbows and spear guns used for other studies[5]. The CO_2 dart projector was also selected due to its precision. The use of large crossbows was not considered due to possible excessive impact or penetration. Poles with biopsy tips were successfully used from sailing vessels, but were ineffective from the inflatable, as the animals rarely surfaced while bowriding (which they also infrequently did), and they always showed moderate avoidance reactions when a pole protruded from our small boat.

A series of factors may have occurred to prevent the arrow from recoiling as it was expected to do. The dolphin was a subadult female (162cm, rostrum to caudal fork) that was surfacing at about 6m from the boat at the time of shooting. Although the charge regulator device of the CO_2 rifle was set to minimum power, the force provided by the first shot of a new cartridge and the perpendicular angle at which the dart penetrated the skin (approximately 90° to the dolphin’s skin surface) may have increased penetration[6]. The stopper (a flat nylon nose piece to limit the depth of penetration; Barrett-Lennard *et al.*, 1996) was not large and effective enough to cause the arrow to recoil once the biopsy tip had entered the blubber. As skin and blubber biopsy samples were previously obtained from common dolphins with darts fired at a similar distance, and under largely similar conditions, it is unclear what caused the dart to enter the dorsal muscle mass. We suggest that the concomitance of several variables, rather than a single factor, may be the reason.

The dolphin looked healthy and behaved normally prior to the biopsy attempt, providing no visual evidence of it being a sick or emaciated individual. The stomach contained nine partly-digested specimens of adult-size *Sardina pilchardus* and one part of a cephalopod beak[7]. However, an important factor to note was that the blubber layer was only 7mm thick (as compared to 18mm of a stillborn common dolphin calf found in the same area). Although the information on the blubber thickness of other freshly-stranded adult and subadult common dolphins in the area is unavailable, the blubber thickness of 20 similarly sized striped dolphins sampled in Spain ranged from 8-25mm in stranded animals (which included some diseased and emaciated animals) and 12-23mm in incidental captures (A. Aguilar, pers. comm.) Blubber thickness of striped dolphins which died during the Mediterranean morbillivirus epizootic - noteworthy because of their extreme slimness and advanced degree of emaciation (Aguilar *et al.*, 1991; Aguilar and Raga, 1993) - was 6-15mm (A. Aguilar, pers. comm.) More information is needed to ascertain whether the thin blubber layer of the dead common dolphin was indicative of poor nutritional conditions or health problems.

DISCUSSION

It seems clear that the death of the common dolphin reported here was not a direct consequence of the wound. As confirmed by the necropsy, the biopsy dart entered the body a maximum of 40-50mm beyond the stopper, producing a wound that was a maximum of 13mm wide (i.e., the diameter of the stopper) and a minimum of 6mm wide (i.e., the diameter of the biopsy tip). The dart was stuck in the muscle mass below the base of the dorsal fin, on the upper-left side of the body, where the muscle mass was thicker. Post-mortem scrutiny of the wound revealed muscle masses surrounding the cut on all sides. Although the lack of radiological equipment made it impossible to ascertain possible fractures of the spine under these field conditions, the mechanics of the accident are not incompatible with indirect vertebral trauma due to sudden displacement of the external blubber and muscular layers. Therefore, the hypothesis of a vertebral trauma leading to subdural haemorrhage, compression of the spinal cord and subsequent paralysis of the tail muscles cannot be ruled out. These events, in turn, may have been the cause of the observed head-up sinking of the animal, the drowning of which was prevented by the prompt rescue intervention by the research team (Table 1). Blood loss appeared minimal. Death followed about 15 minutes after rescue, possibly due to vagal shock with ceased breathing and heart failure as a consequence. This severe shock may have been caused by the stuck dart, by protracted handling, or by both. Handling was initially avoided, but it was considered appropriate to try to save the animal when it suddenly started sinking in a head-up vertical position (Table 1). The possibility of a partial or progressive paralysis of tail muscles was not contemplated at the time of rescuing, as the main concern was to prevent blood loss and sinking, while trying to minimise the shock. The intention was to release the animal immediately after wound haemostasis could be granted. However, death came suddenly and unexpectedly before this could be done.

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[4] In previous experiences with both common and bottlenose dolphins, this biopsy tip never retained samples including muscle fragments or blood traces.

[5] For instance, ‘strong reactions’ by small Delphinidae were reported when crossbows were used, as compared to ‘mid-reactions’ to spear gun biopsy sampling (IWC, 1991).

[6] According to the dealer ‘This rifle is a CO_2 operated dart projector recommended for close range shooting. It is ideal for penned animals (...) by using the power control valve, caged animals can be shot as close as two feet without injury’ (Pneudart Inc., Williamsport, PA; *www.pneudart.com/html/projectors.html*).

[7] A necropsy was performed in order to gain understanding of the mechanisms that caused the death. Nematodes in the liver were found. A number of tissue samples for toxicological, histological and genetic analyses were collected and stored in liquid nitrogen, alcohol, formalin, or frozen at –20°C. Laboratory analyses are underway.

Dolphin catatonia and death as a consequence of stressful events has been documented in several circumstances. These include: (1) catatonia and sinking to the bottom resulting in death by long-snouted spinner dolphins (*Stenella longirostris*) enclosed by a tuna purse-seine net (Myrick, 1988; Norris, 1991); and (2) death during handling operations aimed at live captures for the captive industry or intrusive research purposes (e.g. Klinowska and Brown, 1986; Hoyt, 1992). Individual variability may be an issue, as different individuals from the same species may react differently to similar stressors. Possibly due to individual physiological and psychological factors (Barrett-Lennard *et al.*, 1996), age, size (Peters, 1983; Gauthier and Sears, 1999), gender (Brown, M.R. *et al.*, 1994; Gauthier and Sears, 1999), reproductive state and/or hormonal conditions, illness or concurrent pathologies, behaviour at the time of sampling (IWC, 1991; Barrett-Lennard *et al.*, 1996), previous experience (Barrett-Lennard *et al.*, 1996), or other factors, some animals may be particularly fragile and can either hyper-react or 'shut off' when exposed to potentially stressful situations.

In other research arenas, animal deaths are often associated with commonly accepted research techniques. For example, immobilisation of pinnipeds and other marine and terrestrial mammals, both with and without anaesthetics, has been reported to result in the death of 3-20% of the animals handled (Loughlin and Spraker, 1989; Baker, J.R. *et al.*, 1990; Work *et al.*, 1993; Heath *et al.*, 1996). Even if conducted by experienced personnel, intrusive research at sea focusing on poorly-known species or populations implies levels of risk that may be hard to assess. There was certainly no precedent of cetacean deaths resulting from biopsy sampling in the published literature. For instance, bottlenose dolphins have been sampled with 45-60kg pull crossbows without reported accidents (Cockcroft, 1994; Weller *et al.*, 1997). 'Mid-reactions' and no fatalities have been reported for hundreds of small-sized Delphinidae (including *D. delphis* and *S. coeruleoalba*) sampled with a spear gun (IWC, 1991; A. Aguilar, pers. comm.)

Little evidence was available on the risks associated with the use of dart projectors for biopsy sampling of small-sized species or individuals prior to the event reported here. Aguilar and Nadal (1984) described the excited reaction of one striped dolphin to a stuck dart shot by a spear gun, but reported that 'the new dart proved its efficiency in about 80% of the hits in striped dolphins, and produced neither significant alterations of swimming pattern nor escape behaviour, from which it is assumed that the biopsy technique is essentially painless'. A perpendicular angle has been reported to optimise sample retrieval, minimise behavioural reactions by the target animal, and reduce the risk of stuck darts (Brown, M.W. *et al.*, 1991; Barrett-Lennard *et al.*, 1996). Patenaude and White (1995) suggested that darting should be done opportunistically at close distance to increase precision and avoid the need to adjust aim for flight curve. In addition, it has been stressed that an increased stop-collar size increases aerodynamic drag and wind resistance, and may alter the flight pattern of the arrow (Palsbøll *et al.*, 1991; Patenaude and White, 1995). As reported by Barrett-Lennard *et al.* (1996) for the darts used here, 'the small surface area of the darts was intended to limit the influence of cross winds and air friction on the flight of the dart, so that predictable trajectories could be achieved at low firing velocities'. In a study by Patenaude and White (1995) on white whale (*Delphinapterus leucas*) carcasses, stop-collar diameter was not significantly correlated to wound type. Although appropriate equipment and techniques can clearly reduce the risks associated to biopsy sampling, it is equally clear that researchers embarking on new biopsy sampling studies should be cautious i.e. they should not over rely on experience with other species/populations and should constantly review procedures and equipment in the light of experience.

CONCLUSION

It is important to consider the present case in context. Whilst avoiding even mildly intrusive research techniques may prevent individual accidents, it would also delay or prevent the understanding of threats that may have serious consequences for entire cetacean populations. Non-destructive biopsy sampling often represents the most straightforward, effective and ethically acceptable way to evaluate threats and try to counteract the disappearance of cetacean species (thus replacing any perceived need to conduct lethal research), as is the case for common dolphin populations in the central Mediterranean Sea. That being said, scientists have an obligation to only adopt intrusive research methods after careful review and risk assessment in the light of the precautionary principle; and their decision must be reviewed on a regular basis according to the best available evidence.

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Past and present utilisation of marine mammals in Grenada, West Indies

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ABSTRACT

The exploitation of marine mammals in Grenada dates back to pre-Columbian times. Whaling ships visited Grenadian waters in the 19th century and during the 1920s there was a short-lived attempt to develop a local, modern whaling industry. Since then no exploitative interactions between Grenadians and marine mammals had taken place, until the 1990s when two whalewatching operations were established.

KEYWORDS: EXPLOITATION; WHALING-HISTORICAL; WHALEWATCHING; HUMPBACK WHALE; ATLANIC OCEAN; NORTHERN HEMISPHERE

INTRODUCTION

The history of marine mammal exploitation for many parts of the eastern Caribbean is poorly known. Organised commercial whaling and dolphin fisheries have existed in the southern Caribbean for about two centuries (Caldwell and Caldwell, 1971; Mitchell, 1975; Gaskin and Smith, 1977; Perrin, 1985; Price, 1985; Reeves, 1988; Romero *et al.*, 1997). A recent review of published literature on marine mammals of the Caribbean (Romero *et al.*, 2001), reveals that Grenada has relatively low marine mammal diversity in its waters and little history of utilisation. Although a commercial whaling operation was established there in the 1920s, details are limited and no attempt has been made to comprehensively summarise or analyse the information from pre-Columbian times to the present.

This paper aims to document both exploitation practices and the conservation status of marine mammals in Grenada. It forms part of a long-term study on the distribution and conservation status of cetaceans in the Caribbean. A similar study for Venezuela has been completed and published (Romero *et al.*, 1997; 2001) and work in Trinidad and Tobago is underway. To the best of our knowledge, we review here all historical marine mammal records (cetaceans and sirenians) for Grenada and then analyse the information within its own historical context.

MATERIALS AND METHODS

Field and archival studies were carried out in Grenada between 19 July and 2 August 1999, with later archival studies conducted in the USA. In order to confirm statements made to us by local individuals about the nature and magnitude of the industrial whaling operation at Grenada in the 1920s, Glover Island off the southwest corner of Grenada was explored (Fig. 1), and evidence of whaling operations was documented. Any indication of whaling activity in the area was photographed and/or videotaped. We also visited the National Library, National Archives and the National Museum at St. George's. All available publications, records or remains related to marine mammals were examined and pertinent documentation was photocopied, photographed and/or videotaped. For the sake of precision, the original measurement system has been used when referring to historical measurements.

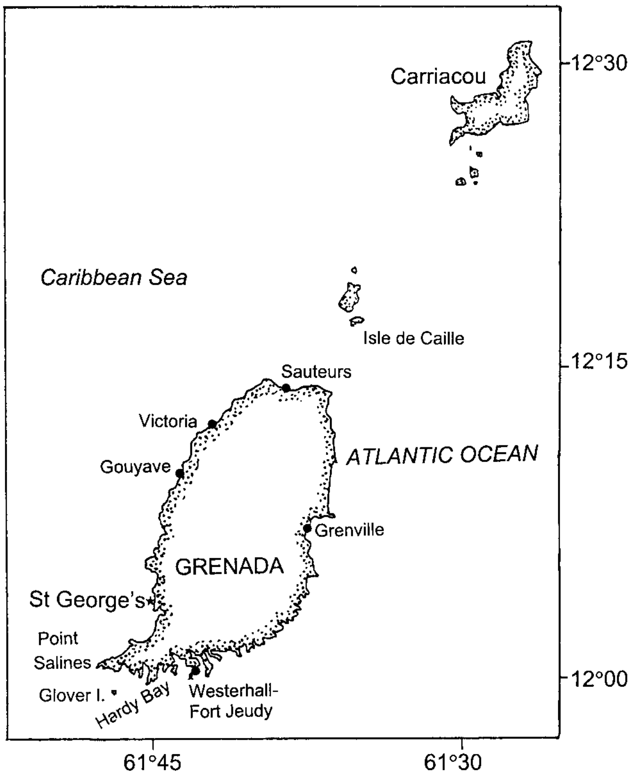

Fig. 1. Map of Grenada, West Indies.

We also visited the following fishing towns in Grenada: Grenville, Sauteurs, Duquesne, Victoria and Hardy Bay (Fig. 1). We interviewed the fishermen and questioned them about past and present practices of marine mammal utilisation using an abbreviated form of questionnaire similar to that used by Dolar *et al.* (1994). All interviews were videotaped.

We went aboard the two whalewatching operations in Grenada: the *Starwind III* off St. George's and the Kido Project off Carriacou and interviewed the crews in charge of the operations. We also explored the coast of Grenada accessible by four-wheel drive vehicle in search of potential places for land-based whalewatching.

RESULTS

Historical account

Pre-Columbian era and Colonial times

Archaeological remains indicate that the West Indian manatee (*Trichechus manatus manatus*) was distributed along the Lesser Antilles and was used by the indigenous people inhabiting those islands (Ray, 1960; Wing *et al.*, 1968; Watters *et al.*, 1984; Lefebvre *et al.*, 1989; Wing and Wing, 1995). A piece of manatee rib was examined from the National Museum.

Historical accounts also support the contention that manatees were hunted, using harpoons, by the local inhabitants of Grenada and neighbouring islands up to Colonial times (Du Tertre, 1667; Dapper, 1673; Labat, 1742; Knight, 1946; Steward, 1948; Bullen, 1964; Wing and Wing, 1995; for additional citations of pre- and post-Columbian uses of manatees in the Caribbean see McKillop, 1985). It has not been possible to determine the exact date at which manatees became extinct in Grenada. However, the available references indicate that they could be found until at least the 17th century.

Commercial whaling era

The first documentation of commercial whaling in Grenadian waters dates back to 1857. Knight (1946) reports that in the early months of that year, as many as eight American whalers were seen anchored off St. George's, Grenada's capital, with their boats fully employed. The formation of a local whaling company was discussed, but nothing developed. At the beginning of the 20th century, a few whales were harpooned every winter by local (artisanal) fishermen in the south of Grenada (Jacobsen, 1981).

During the heyday of New England whaling, whalers visited Caribbean waters for humpback whales (*Megaptera novaeangliae*) and occasional sperm whales (*Physeter macrocephalus*), and at the same time recruited a few extra men from among the seamen/fishermen in the Grenadines. A Scotsman named Wallace settled at Bequia, the nearest of the Grenadines to St. Vincent, and after losing his savings in sugar started a small whaling operation using the New England methods of that date. His activities spread to Grenada (Isle de Caille and St. George's), St. Lucia, Barbados and Trinidad (Monos Island) (Brown, 1945; Adams, 1970).

The first attempt to develop large-scale whaling took place around 1920, when C.V.C. Horne, Manager of the Colonial Bank in Grenada, bought Glover Island after observing a great number of whales in its waters. He invested considerable capital in an effort to establish a small whaling station on the island and obtained a whaling licence from the government. Catches were made from rudimentary sail boats. It is unclear whether these whalers were Grenadian residents or rather from the nearby Grenadine Islands. Fishers from Bequia were known to whale in Grenadian waters (Adams, 1970). In 1920, an undetermined number of humpback whales (probably between eight and twelve), were captured, yielding 1,620 gallons of oil, worth £461. During 1921, a single humpback was taken, yielding 160 gallons of oil (value £50) which were exported to Trinidad to make soap. While there are no whaling records for 1922, at least five humpbacks were caught in 1923, yielding 2,110 gallons worth £295. A total of 1,760 gallons of oil (value £233) was exported to the United Kingdom and 350 gallons (value £162) to Barbados (Grenada Blue Book, 1923; Fenger, 1958; Mitchell and Reeves, 1983).

Apparently, Horne thought that the operation could be expanded but he needed technical (and probably financial) support in order to fully industrialise his operations. Correspondence between Minister Vogt of the Colonial Office and the Norwegian Whaling Association shows that he may have contacted people in Norway as early as 1921 (a year after his first successful whaling campaign) with the aim of establishing a modern whaling operation in Grenada, although nothing came of it at the time (Tønnessen, 1969). There is a reference to Horne visiting Oslo and forming the Grenada Whaling Co., Ltd., with a capital of £25,000 (Anon., 1928). However, we have been unable to trace his involvement in Grenadian whaling after that.

By 1923, Winge & Co., a Norwegian whaling company from Oslo had started to participate in this venture. By February of that year, Norwegian whaler Morten Andreas Ingebrigtsen, with ties to that company, applied for a licence through the Ministry of Foreign Affairs to whale in the Lesser Antilles, writing in the application that 'I had been in the whaling business all my life.' [English in the original]. To study the feasibility of this operation, the famous Norwegian Arctic explorer Captain Otto Sverdrup and the Director of Winge & Co., Halfdan Bugge, visited Grenada in the winter of 1923-1924. Sverdrup observed the whales (he counted 26), studied the sea currents and recommended that a modern post be set up on the south of the island (Tønnessen, 1969). Winge & Co., through its subsidiary, the Grenada Whaling Co., acquired Glover Island as a base for whaling factory operations.

Construction of the modern whaling station apparently began in October 1924. Examination of the only known picture of the building together with our own exploration of its remains on Glover Island indicate that this was a large, two-storey building, comparable in size to similar whaling establishments of the time and designed to carry out a large whale oil operation. The first whaling season commenced on 15 January 1925 with two modern steam-driven whaling vessels from Norway. Each vessel was fully equipped and capable of towing five whales. A harpoon gun was mounted on a platform at the bow of each vessel, with a killing range of 50ft. These ships could cruise at speeds of up to 11 knots, used the latest explosive harpoons and employed three harpoonists (Marsland, 1925; Jacobsen, 1981).

After being pumped with air to prevent them from sinking, the whales were drawn alongside the ships. Upon arriving back on the island, the dead whales were drawn up a large concrete chute onto the 'plain', which consisted of a flat wooden platform sufficiently large to accommodate several whales. Here the flensing took place; the blubber being the most valuable part, was kept separate, cut up into slices and conveyed by means of an elevator into the blubber extracting plant (Marsland, 1925).

The Colonial Government of Grenada took a number of legal steps to regulate and tax the whale industry. Thus, on 2 February 1925, it published Ordinance Number 15, called the Whale Fisheries Ordinance, which had been approved by the Governors in Council on 26 January 1925. The regulations were quite elaborate. The first five articles were set out to define the activities and permits. Article 5(2) established a whaling license fee of £25. Section (3) stipulated that the holder of the whaling license was entitled to operate one whale catcher and one land station or one floating factory. They were also very specific about the handling of the different parts of the whales. Article 9, for example, read that 'Floating factories or land stations shall utilise the following parts of all whales taken under license namely: (a) head; (b) jawbones; (c) tongue; (d) tail (from vent to the flukes); and (e) inside fat'. Article 10 established that the number of flensed whale carcasses waiting to be dealt with at one time, either at a land station, or attached to any vessel or mooring, should not exceed twelve. Article 11 specified that 'the whaling officer may prohibit the use of any licensed whale catcher for taking whales when, in his opinion, the further taking of whales would lead to an accumulation of whale matter that could not be utilised without undue waste'. Finally, Article 13 read that 'No person shall kill, hunt, or take or attempt to kill, hunt, or take any sperm whale of the length less than 25ft or any whale calf or female whale accompanied by a calf' (Grenada Gazette, 1925).

Apparently, local authorities were concerned with carcass handlings as on 8 April 1925, shortly before the end of the first major whaling operation for that year, they amended Article 9 by establishing that 'Land stations shall utilise the whole carcass of all whales taken including bones without waste' (Grenada Gazette, 1925). This may have been due to the well known foul smell produced by oil blubber extraction and the rotten carcasses of whales. During our visit to Glover Island we could not find any remains of any kind from whales or any other marine mammal. Locals told us that the few left behind were taken by visitors after the whaling operation ceased.

The first whaling season took place between 15 January and 4 April 1925 where 105 whales were taken; 102 humpbacks and two Bryde's whales (*Balaenoptera edeni*), one of which contained a foetus which was counted as an additional animal. This resulted in 112,963 gallons of whale oil, valued at £16,890, which was exported to Norway (109,399 gallons = £16,200), the United Kingdom (3,435 gallons = £650), Barbados (80 gallons = £12) and Demerara, in today's Guyana (49 gallons = £8).

Once the oil factory was completed towards the end of 1925, the station was equipped for the manufacture of 'whale manure (guano)' in the following year (Knight, 1946), probably in response to the amendment mentioned previously. Part of the whale meat was sold for human consumption and the rest was boiled down to extract the last ounce of oil (Marsland, 1925).

The second season took place from 10 January to 30 April 1926. Despite the addition of a third vessel and a fourth harpoonist, only 72 whales (all humpbacks) were captured. The decline in catches was attributed by some to bad weather and other 'unfavourable conditions' (Anon., 1928), although the most prevalent opinion was that the fishery was abandoned due to scarcity of whales (Anon., 1928; Jacobsen, 1981; Mitchell and Reeves, 1983). According to information from the government records, we believe that the figures of 70 and 71 whales killed, given by Mitchell and Reeves (1983) and Tønnessen (1969), respectively, may be erroneous. In any case, the reduced number of whales captured made the operation uneconomical. Apparently this was due to the fact that the whales were so 'shy' that it was difficult to get within shooting range. Experienced harpooners said that they would need 37mm cannons to accurately shoot the whales (Tønnessen, 1969).

Catches in 1926 yielded 108,055 gallons of whale oil, valued at £14,258. The oil was exported to Holland (107,815gallons = £14,230) and Trinidad (240 gallons = £28). Some 418 bags (200 tons) of 'manure' or 'guano' to be used as fertiliser, valued at £418, were exported to Trinidad (Grenada Blue Book, 1926).

The whaling operation at Glover Island was directed from Oslo by Halfdan Bugge while J.A. Hojem was the manager on site. Seventy men were employed, in addition to the crews of the vessels, each of which carried 11 men. According to our interviews with local fishermen, as many as 600 boilers were installed and up to 100 people were employed, including women. Among the foremen there were ten Norwegians and six Americans living in the Main House. Our visit to Glover Island confirmed the plausibility of the great magnitude of this operation.

By 1925, whaling in the nearby Grenadines had also come to a halt. The two whaling establishments at Canouan, and those located at Prune Island and Frigate Rock had suspended operations. Only a handful of boats based at Friendship Bay, Bequia, continued to hunt humpbacks, albeit rather unsuccessfully, in the ensuing decade (Adams, 1970). No operations were carried out in Grenada during the 1927 season. All attempts to re-finance the company failed (Tønnessen, 1969). This coincided with a more general depletion of whale stocks in the Northern Hemisphere (McHugh, 1977). By 1928, the whaling industry at Glover Island was finally abandoned and the factory was dismantled in 1929 (Knight, 1946).

Not only was there a strong decline in whale populations, as evidenced by contemporary reports cited earlier, but major changes were also affecting the whaling industry at that time. In 1925, the installation of a ramp on factory ships allowed the catch to be processed on board, making land stations like the one at Glover Island unnecessary.

Current utilisation

According to local fishermen, humpback whales are occasionally seen in local waters during the winter. However, we found no evidence of any marine mammal captured either intentionally or accidentally by Grenadian fishermen. In Duquesne, we were told that a dolphin had stranded in 1993 and that its meat had been consumed by the locals. We could find no other report, written or oral, of cetacean strandings in Grenada. Pictures of an artisanal whaling operation displayed at the National Museum must have been taken elsewhere, since the landscape in the background was flat and arid, unlike any coastal areas of Grenada and its smaller islands.

Many of the interviewed fishermen had difficulty identifying whales and dolphins from posters and books. With the exception of the 'blackfish' (short-finned pilot whale, *Globicephala macrorhynchus*), no common names were familiar to the interviewees. Only on two occasions were we told that dolphins were called 'papas', a phonetic derivative of 'porpoise'. One fisherman referred to dolphins as 'Flipper', which is obviously due to a foreign cultural influence.

The only current utilisation of marine mammals is in the form of whalewatching. At the time of our visit, there were only two organised operations, one off Grenada and the other off Carriacou. Both operations, which take place year-round, seem to be successful since they have been in business for several years. In both cases they seem to be opportunistic, targeting local and apparently resident populations of sperm whales and dolphins. Each employ no more than four people as boat crews.

Whalewatching has become an increasingly popular and profitable enterprise worldwide (Papastavrou, 1996). Although whalewatching has the potential to harass marine mammals, proper procedures can drastically reduce the impact of this activity on cetaceans (Evans, 1996).

There is also the potential for 'non-harassing', whalewatching from land in southwestern Grenada. We found that at least two locations, Westerhall-Fort Jeudy and Blow Hole at Point Salines, have cliffs from which humpbacks can be observed during the winter season (Lesley Sutty, pers. comm.), which is at the peak of the tourist season in that country.

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Mysticete whale abundance and observations of prey associations on the central Bering Sea shelf

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ABSTRACT

Visual surveys for cetaceans were conducted along transect lines in the central Bering Sea in association with a groundfish stock assessment survey from 5 July to 5 August 1999. There were 125 sightings of single or groups of mysticete whales during 6,043km of survey effort. Fin whales were most common (60% of all sightings), with distribution clustered along the outer continental shelf break near the 200m isobath. In addition, there were 27 sightings of minke whales and 17 sightings of humpback whales. Minke whales were primarily found along the upper slope in water 100-200m deep, while humpbacks clustered along the eastern Aleutian Islands and near the USA/Russian Convention Line southwest of St. Lawrence Island. Abundance estimates for fin, humpback and minke whales were: 4,951 (95% CI = 2,833-8,653); 1,175 (95% CI = 197-7,009) and 936 (95% CI = 473-1,852), respectively. These three species were the only ones for which sufficient on-effort sightings were available to estimate abundance. Sei whales, a gray whale and a pair of northern right whales were also seen. Although right whales have been seen in this area before, some behavioural details are provided here because observations of these whales remain rare.

KEYWORDS: MYSTICETE WHALE; FIN WHALE; MINKE WHALE; HUMPBACK WHALE; NORTH PACIFIC RIGHT WHALE; DISTRIBUTION; ABUNDANCE; BERING SEA

INTRODUCTION

There have been few broad-scale surveys for whales in the central Bering Sea that were not associated with commercial whaling (e.g. Wada, 1981) and most contemporary references to mysticete whale distribution and abundance in this region rely on catch records (e.g. Springer *et al.*, 1996; 1999). North Pacific right whales (*Eubalaena japonica*), fin whales (*Balaenoptera physalus*) and humpback whales (*Megaptera novaeangliae*) were harvested predominantly south of the Aleutian Islands in the North Pacific, but there were also substantial takes in the central Bering Sea (Nasu, 1974; Miyashita *et al.*, 1995; Brownell *et al.*, 2001). From 1966-1990, minke whale (*Balaenoptera acutorostrata*) sighting rates from whaling or whaling-support vessels were highest in the western Pacific and Sea of Okhotsk, with comparatively few whales reported in the central Bering Sea (Miyashita *et al.*, 1995). Due to lack of broad-scale surveys dedicated to obtaining abundance estimates, it has been impossible to determine: (1) if populations of mysticete whales are recovering from the commercial harvests of the 20th century; and (2) their role in the ecology of the Bering Sea (Livingston, 1993).

A rare sighting of a small group of North Pacific right whales was made during a groundfish assessment survey in the eastern Bering Sea in July 1996 (Goddard and Rugh, 1998). This sighting prompted efforts to put marine mammal observers onboard a fishery research vessel in summer 1997. This opportunistic survey proved successful, as right whales were sighted and photographed in the anomalous coccolithophore (*Emiliania huxleyi*) bloom prevalent in the eastern Bering Sea that year (Vance *et al.*, 1998; Tynan, 1999). In 1999, scientists from the Alaska Fisheries Science Center/Resource Assessment and Conservation Engineering (AFSC/RACE) Division conducted another in a series of acoustic-trawl surveys for walleye pollock (*Theragra chalcogramma*) on the Bering Sea shelf. Biologists from the AFSC/National Marine Mammal Laboratory (NMML) joined the second leg of that cruise and conducted a visual survey along the lines RACE had developed for the pollock assessment. This opportunity provided a means to assess the central Bering Sea shelf for mysticete whales.

METHODS

Visual survey protocol

A line-transect survey for cetaceans was conducted from the flying bridge of the NOAA ship *Miller Freeman* (66m, 215ft), while the ship was in transit between trawling sites over the central Bering Sea shelf (Fig. 1). The survey design consisted of north-south transect lines spaced 37km (20 n.miles) apart, except in the ‘Horseshoe Area’ where spacing was 18.5km (10 n.miles). The survey proceeded from east to west starting at 171°26’W and ending at 178°55’W, with some survey effort conducted northeast of the Pribilof Islands and near Unimak Island en route to and from port at Dutch Harbor, Alaska. The vessel maintained a speed of 10-11 knots between trawling sites. Effort began and ended with available light (07:30-22:30 hours local time). Standard line-transect survey protocol was adopted (Barlow, 1988), except that the observers did not rotate stations. When weather conditions permitted (i.e. dry, visibility ≥ 1 km), two primary observers maintained a continuous watch for marine mammals at starboard and port stations on the flying bridge using 25 × 150 power binoculars (Fig. 1: on-effort). A data recorder, stationed between the primary observers, searched by scanning both sides of the ship with naked eye and using 7 × 50 hand-held binoculars. Observer eye height was 12m above the water line. The radial distance to sightings was estimated using the angle below the horizon measured with reticles in the binoculars (Lerczak and Hobbs, 1998 but also see associated Errata), or estimated by eye when animals were very close to the ship. The radial angle to the sighting was measured using an angle ring mounted on the 25 × 150 power binocular support column.

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In poor weather (i.e. rain, visibility ≤1 km), or areas of patchy dense fog, one observer maintained watch using hand-held binoculars from the bridge (Fig 1: bridge-effort). Survey effort was suspended whenever visual conditions deteriorated to ≤200m and while RACE biologists conducted fishing operations (Fig. 1: off-effort).

Data collection, oceanographic correlates and analysis

Variables related to marine mammal survey effort and sightings were recorded on a laptop computer and updated whenever conditions changed. At 5-minute intervals, the program automatically updated fields of time, date, latitude, longitude and other variables if they remained unchanged. Environmental and oceanographic data were obtained from instruments maintained by the RACE scientists. Along-track measurements of water temperature, salinity and fluorometer were recorded at 5-minute intervals from the ship's flow-through system, which sampled seawater at about 3m depth. Wind direction and speed, vessel heading and vessel speed were also recorded every five minutes. A bongo tow net system (60cm bongo frame with 505µ mesh nets and a 40kg lead weight) was deployed from the ship's starboard winch to collect samples in the vicinity of right whales in the coccolithophore bloom.

Mysticete whale abundance was estimated using line-transect analysis for each species with 10 or more on-effort sightings. Bridge-effort and off-effort sightings were not used for abundance estimation, but were plotted to depict species' distribution. Effective strip width, density and abundance were estimated using the program DISTANCE (Laake *et al.*, 1993). Abundance, N, was calculated as:

$$N = \frac{A\bar{s}n}{WL}$$

where:

A is the size of the study area;
$\bar{s}$ is the average number of whales per useable, on-effort sighting;
n is the number of useable on-effort sightings;
W is the effective strip width; and
L is the total length of the useable effort segments.

The study area was defined as the area enclosed by a boundary 10km beyond the limits of the survey tracklines (Fig. 1), calculated as 343,169km^2 using ArcView^{TM} (3.1).

The perpendicular distance between a sighting and the trackline was estimated as the product of the radial distance to sightings and the sine of the radial angle of the sighting. Perpendicular sighting distances were grouped into 0.5km bins. Where a gap of 1km or greater in the distribution of sightings from the trackline occurred, the maximum distance was truncated to eliminate the gap. Sightings beyond the truncation point were removed from the analysis. The probability of sighting with respect to perpendicular distance

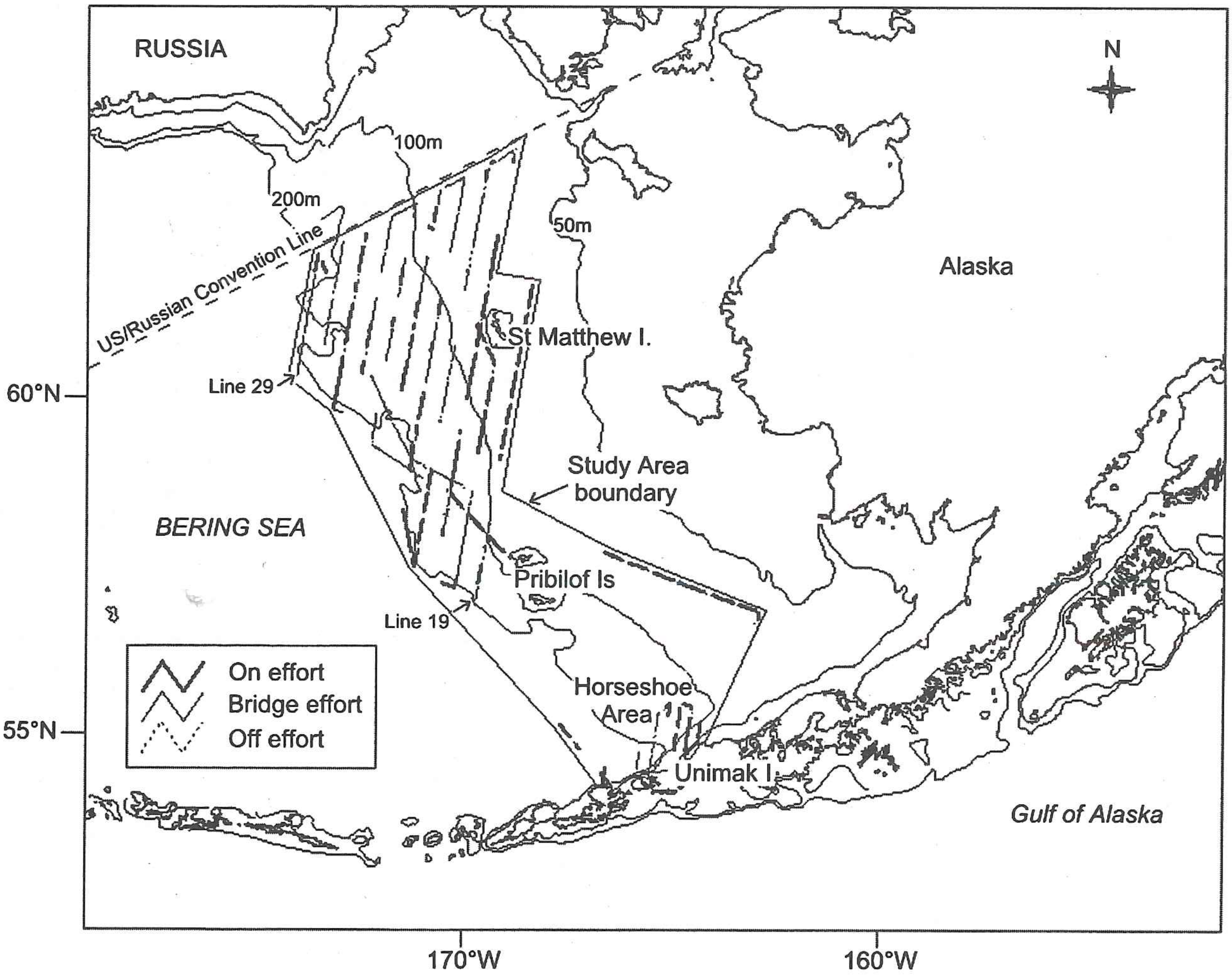

Fig. 1. Survey track of the NOAA ship *Miller Freeman* in the central Bering Sea shelf. See text for trackline designations: on-effort, bridge-effort and off-effort.

Table 1

Mysticete whale sighting summary.

Species	No. sightings	No. whales	% Total sightings
Fin whale	75	346	60
Minke whale	27	37	22
Humpback whale	17	39	14
Sei whale	4	6	3
Gray whale	1	1	0.5
N. Right whale	1	2	0.5

from the trackline was modelled using the half-normal and hazard-rate curves, using either the cosine or Hermite polynomial corrections and assuming that the probability of sighting a group on the trackline was 1. Akaiki Information Criteria (AIC) were used to determine the best model fit. The strip width was estimated as twice the integral of this curve over the perpendicular distance from the trackline to the truncation point. Tracklines began and ended whenever there was a significant shift in survey effort as indicated by changes in sighting conditions (visibility, Beaufort sea state), personnel, or vessel speed and direction.

RESULTS

The cruise began and ended in Dutch Harbor, Alaska and extended from 5 July to 5 August 1999. Although the acoustic trawl effort for pollock began on transect line 19 (56°20'N, 171°26'W) and ended with transect line 29 (60°65.9'N, 178°91.68'W), survey effort for marine mammals began on transit to and from these way points. The entire track of the marine mammal survey, including transect lines 19-29, the Horseshoe Area, and transits to and from Dutch Harbor, covered 6,043km (Fig. 1). Of the total track, 2,354km (39%) was surveyed on-effort, 2,017km (33%) was conducted by one person on the bridge in marginal weather conditions (i.e. bridge-effort), and the remaining 1,672km (28%) of trackline was covered while observers were off-effort.

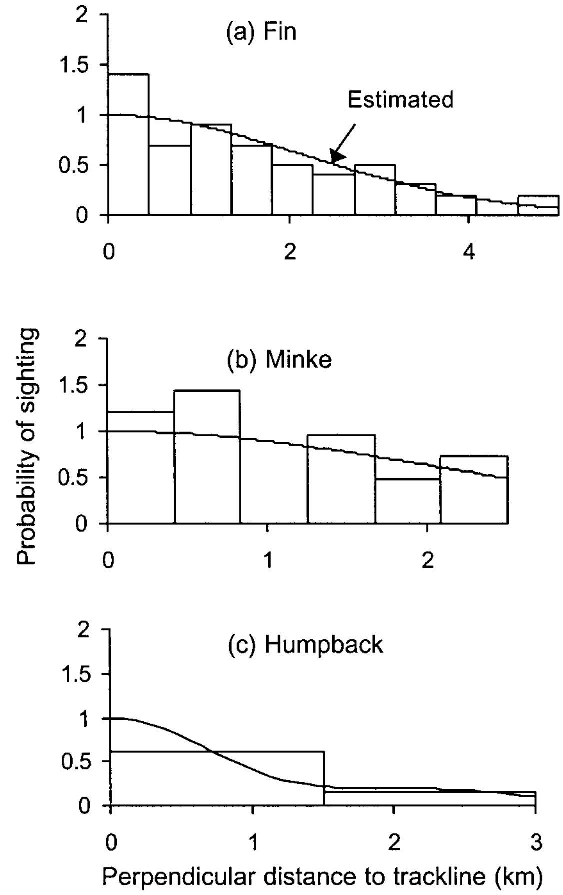

Fig. 2. Distribution of perpendicular sighting distances for fin, minke and humpback whales, with best-fit detection function [G(x)] curves.

Mysticete whale distribution and abundance

There was a total of 125 mysticete whale sightings; most (60%) were fin whales (Table 1). Of the 75 fin whale sightings, 58 were on-effort and used to estimate abundance (Table 2). Using a truncation distance of 5km (Fig. 2), the estimated abundance of fin whales was 4,951 (95%

Table 2

Abundance estimates. [ ] = Number of on-effort sightings.

Parameter	Point estimate	Standard error	% CV	95% Confidence Interval	
(a) Fin whales [58]				(Lower)	(Upper)
Truncation distance (km)	5.0				
Effective strip width (km)	2.6	0.3	10	2.1	3.2
Sightings per km	0.024	0.006	23	0.016	0.038
Sightings per km^2	0.0046	0.0012	25	0.0029	0.0076
Average pod size	3.1	0.4	14	2.3	4.1
Whales per km^2	0.014	0.004	29	0.008	0.025
Estimated abundance	4,951	1,434	29	2,833	8,653
(b) Humpback whales [10]					
Truncation distance (km)	3.0				
Effective strip width (km)	1.2	0.5	39	0.5	2.8
Sightings per km	0.004	0.004	105	0.001	0.023
Sightings per km^2	0.002	0.002	112	0.000	0.011
Average pod size	1.9	0.3	17	1.3	2.8
Whales per km^2	0.003	0.004	113	0.001	0.020
Estimated abundance	1,175	1,325	113	197	7,009
(c) Minke whales [20]					
Truncation distance (km)	2.5				
Effective strip width (km)	2.0	0.4	19	1.3	3.0
Sightings per km	0.0084	0.0019	22	0.0055	0.0130
Sightings per km^2	0.0021	0.0006	30	0.0012	0.0037
Average pod size	1.3	0.3	19	1.0	1.9
Whales per km^2	0.0027	0.0010	35	0.0014	0.0054
Estimated abundance	936	331	35	473	1,852

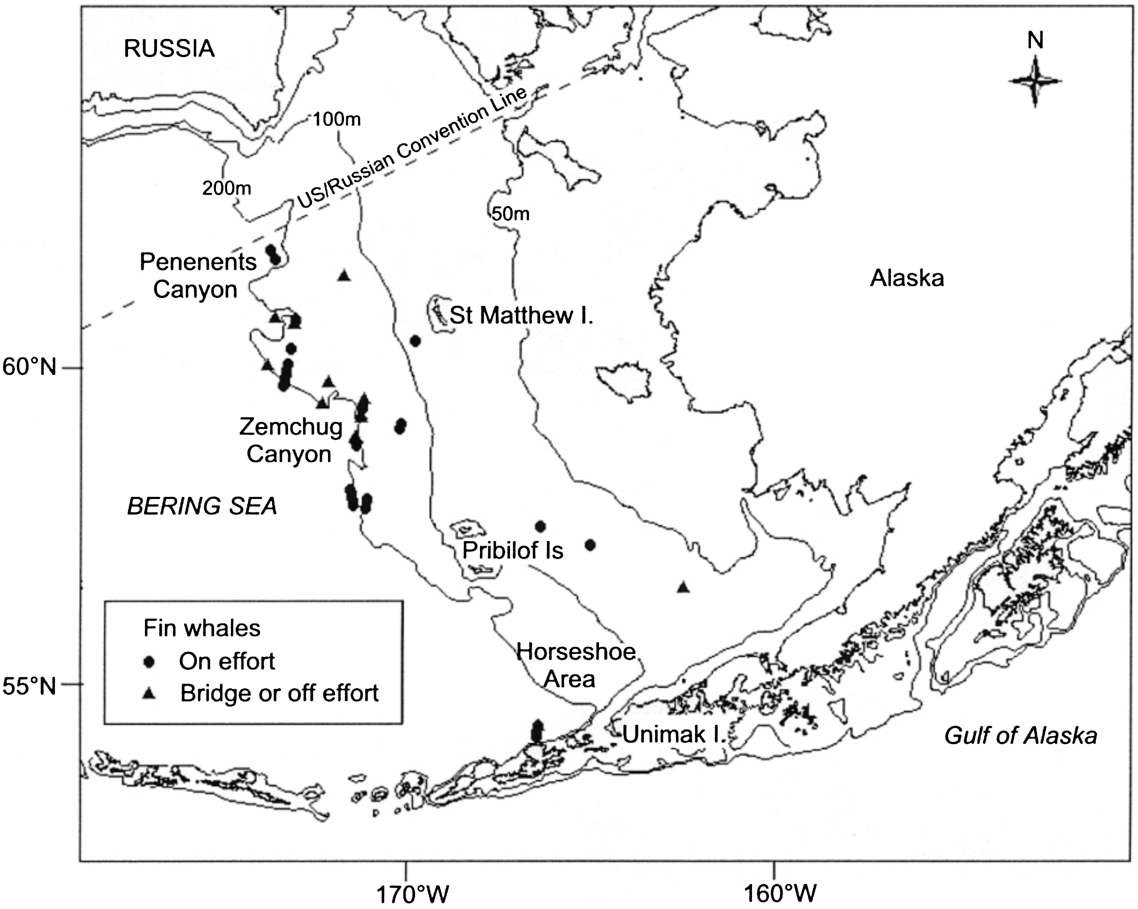

Fig. 3. Distribution of 75 sightings representing 346 fin whales.

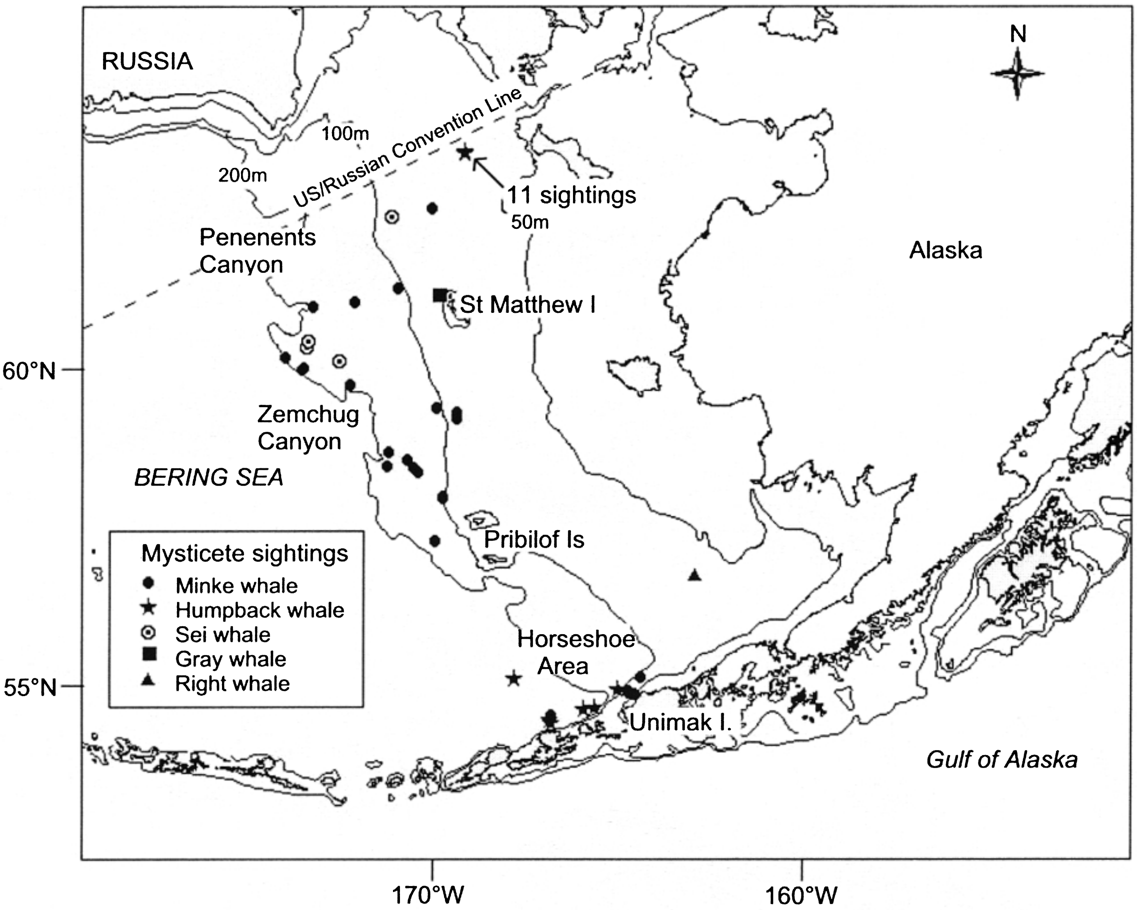

Fig. 4. Distribution of: 27 sightings representing 37 minke whales; 17 sightings representing 39 humpback whales; 4 sightings representing 6 sei whales; and single sightings of a gray whale and a pair of Northern right whales.

CI = 2,833-8,653). Fin whale sightings were clustered along the outer Bering Sea shelf break, primarily near the 200m isobath and near Zemchug Canyon (Fig. 3).

There were 27 sightings of minke whales and 17 sightings of humpback whales made during the cruise. Minke whales were distributed along the upper slope in water 100-200m deep, while humpbacks clustered along the eastern Aleutian Islands and near the USA/Russian Convention Line southwest of St. Lawrence Island (Fig. 4). Twenty of the minke whale sightings and 10 of the humpback sightings were on-effort, and used to estimate abundance (Table 2). Using truncation distances of 2.5km and 3km, respectively (Fig. 2), the estimated abundance of minke whales was 936 (95% CI = 473-1,852) and that of humpback whales was 1,175 (95% CI = 197-7,009). The wide confidence interval for the humpback whale estimate (CV = 1.13), reflects the paucity of on-effort sightings.

There were four sightings of six sei whales (*Balaenoptera borealis*); three sightings of five sei whales near the minke whales seen southeast of Pervenets Canyon shoreward of the 200m isobath, and one sighting of a lone sei whale closer to the Pervenents Canyon near the 100m isobath (Fig. 4). In addition, there were single sightings each of a gray whale (*Eschrichtius robustus*) near St. Matthew Island (60°35.19'N, 173°24.17'W), and a pair of North Pacific right whales in the eastern Bering Sea (56°58.33'N, 163°27.64'W; Fig. 4). Although North Pacific right whales have been seen in this area before, some additional details of this encounter are provided because observations of these whales are rare (see review in Brownell *et al.*, 2001).

North Pacific right whale observations

On 31 July 1999, an extensive coccolithophore bloom was observed during a ten-hour, eastbound transit that began at approximately 12:30 local time (57°21.78'N and 166°28.07'W; Fig. 1). The vessel was in the bloom at least until sunset, approximately 22:45 local time (56°52.12'N and 163°32.92'W). Two North Pacific right whales were initially sighted by naked eye near the horizon, breaching at least five times. Species identification was confirmed with hand-held and subsequently 25 × 150 binoculars. The pair was seen near the only right whale sighting on Leg 1 of the *Miller Freeman* cruise (conducted in June 1999) and, as in 1997, the whales were well within the coccolithophore bloom. The right whales were approximately 5km (2-3 miles) from four fin whales and in the vicinity of right whale sightings made by researchers conducting aerial, vessel and acoustic surveys from 8-18 July 1999, just ten days before this sighting (R. LeDuc, pers. comm.).

The right whales remained within one body length of each other throughout the approximately one-hour observation period. They did not appear to respond adversely to the vessel and actually approached and swam across the bow, passing within 250m of the ship (Fig. 5). Observed behaviours included breaching, close contact, rolling to extend a pectoral fin in the air, a fluke-up dive, shallow dives of short duration (1-5 minute down time average) and slow-swimming in tandem. Both whales appeared healthy and robust, were similar in length (roughly 12-14m) and girth, and were free of natural or fishery gear-interaction scars or markings. Oddly, both animals lacked

1. V-shaped blow from foreground animal.

2. Foreground animal at peak of surfacing.

3. Background animal begins to surface.

4. Background animal blows.

5. End of surface sequence.

Fig. 5. Surfacing sequence for a pair of right whales as they passed the bow of the NOAA ship *Miller Freeman* on 31 July 1999.

white-coloured callosities typically associated with right whales. Instead, their raised callosity patches were a dark, rust-coloured hue.

Water depth at the whales' location was 70.6m, water temperature was 8.6°C, and salinity was 31.753 psu. Shortly after photographing the whales, two bongo nets (505μ mesh) were deployed and a tow taken near the bottom and within the coccolithophore bloom. During the tow, the whales remained within about 2km (1 n.mile) of the vessel. Samples from both nets collected from a bottom depth 70-71m included jellyfish and larval pollock.

Prey associations

Throughout the cruise there was often a positive association between mysticete whale aggregations and concentrations of zooplankton, euphausiids, pollock and other fish observed on the echosounder by RACE scientists from the Midwater Assessment Conservation Engineering (MACE) programme. Elevated fluorometer readings were often noted during these observations. Although a full analysis will be the subject of a future paper, it seems useful to summarise some of the more interesting observations here, especially those on the middle shelf along the 200m contour and adjacent to canyons.

On 14 July 1999 (line 21: 62°59.95'N, 173°58.75'W), large aggregations of 3-5 inch arctic cod (*Boreogadus saida*) occurred jointly with an aggregation of 17 humpback whales (in five groups), a group of eight killer whales *(Orcinus orca*), and approximately twenty species of sea birds, with pomerine jaegers (*Stercorarius pomarinus*) the dominant species. Five killer whales were observed chasing a single humpback whale, which responded by tail-slapping vigorously. Unfortunately, the vessel then left the area so observers were unable to determine the outcome of the killer whale/humpback whale interaction.

On 16 July 1999 (line 22: 57°14.97'N and 173°18.55'W), the MACE echosounder detected *ca* 40km (over 25 miles) of zooplankton and euphausiids echosign near Zemchug canyon (bottom depth 135-150m), including 7-8km (4-5 mile) intervals of strong fish echo within the longer stretch of zooplankton. Concurrently, marine mammal observers documented aggregations of 28 fin whales (in 10 groups) and 55 Dall's porpoise (in 15 groups), short-tailed shearwaters, fork-tailed storm petrels, Leach's storm petrels, long-tailed jaegers and Laysan albatross.

On 26 July 1999 (line 26: 58°39.38'N and 176°50.17'W), the MACE echosounder detected similar prey aggregations near Pervenents Canyon (bottom depth 150-200m), where dense pollock schools at times occupied the entire water column. Aggregations of 59 fin whales (in 21 groups), seven minke whales (in two groups) and three sei whales (in two groups) were documented, with all species lunge-feeding at the surface. The whales were accompanied by thousands of seabirds. Dominant bird species included short-tailed shearwaters, fork-tailed storm petrels, pomerine jaegers, Laysan albatross and an enormous flock of red phalaropes.

The largest aggregation of fin whales (> 100 animals) was seen off-effort on 27 July (line 27: 59°36.40'N and 177°09.80'W), within a 8-10km (5-6 mile) stretch of dense fish echosign within the coccolithophore bloom. Water temperature ranged from 6.0-8.9°C and peaked at 8.9°C; water depth ranged from 66-71m. Other marine mammals seen in the coccolithophore bloom included northern fur seals (9), harbour porpoise (nearly 30% of all sightings), and the pair of right whales (Fig. 4). Surprisingly, there were not

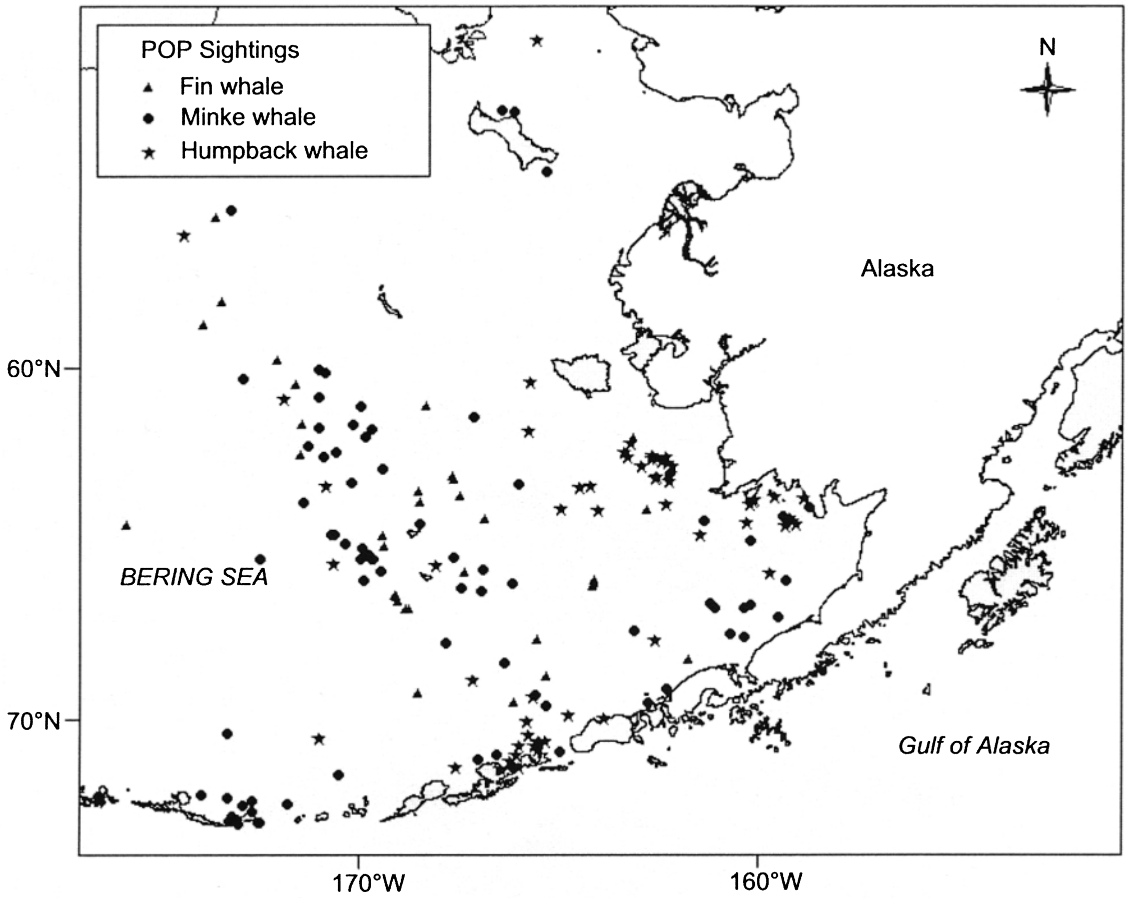

Fig. 6. Distribution of fin, minke and humpback whales in the central and eastern Bering Sea from NMML Platforms of Opportunity (PoP) database. Data from opportunistic sightings during June and July, 1980-99.

many seabirds. Species observed included the glaucous-winged gull, parasitic jaeger, Arctic tern and possibly an Aleutian tern.

DISCUSSION

The 1999 cruise aboard the NOAA ship *Miller Freeman* provided a valuable opportunity to conduct a line-transect survey for marine mammals in the central Bering Sea, and resulted in sufficient sightings data to support the calculation of abundance estimates for fin, minke and humpback whales. However, these are clearly *preliminary* in that the survey covered only a portion of the entire Bering Sea, and because the abundance estimates were not corrected for a number of factors including animals missed on the trackline, animals that were submerged, possible reaction to vessels etc. To emphasise this, a plot of June/July 1980-99 sightings of the three species was compiled from the National Marine Mammal Laboratory (NMML) Platforms of Opportunity (PoP) database (Fig. 6). Although unrelated to survey effort, the broad distribution of sightings for each species provides a clear indication that whales detected during any one survey will surely under-represent the overall distribution and abundance of mysticete whales in the eastern and central Bering Sea.

Until now, however, there has been no estimate of fin whale abundance in the Bering Sea (Hill and DeMaster, 1999). The uncorrected abundance estimate of 4,951 whales (95% CI = 2,833-8,653) reported here indicates that the Bering Sea is an important habitat for fin whales. From previous surveys (e.g. Buckland *et al.*, 1992) no correction is likely for fin whales and this, combined with the large number of sightings, suggests the estimate obtained represents a reasonable estimate of the number of fin whales in the research area at that time. For comparison, Ohsumi and Wada (1974) estimated 14,620 to 18,630 fin whales in the entire North Pacific in the late 1970s. Fin whale sightings were concentrated along the shelf edge and were often associated with dense concentrations of zooplankton and fish. Similarly, Nasu (1974) reported that fin whales in the Bering Sea were commonly associated with the oceanic front that occurs between water masses at the shelf break, while Springer *et al.* (1999) also reported fin whale distribution in the sub-Arctic North Pacific (based on whaling records) to coincide with zooplankton biomass.

Minke whales in the eastern North Pacific are separated into the Alaska stock and the California, Oregon and Washington stock based on distribution (Hill and DeMaster, 1999). During the *Miller Freeman* survey, minke whales were distributed throughout the study area, including nearshore regions (e.g., Unimak I.) and the upper shelf, suggesting widespread use of the Bering Sea. While there are reports of minke whale aggregations elsewhere in the Bering Sea, such as along the Chukotka coastline (e.g. Melnikov, 2000), there has been no abundance estimate available for the Alaska stock of minke whales in the Bering Sea. Therefore, the estimate of 936 whales (95% CI = 473-1,852), although uncorrected and covering only a small portion of the stock's range, provides a baseline minimum estimate for this population. Experience from other surveys (e.g. Schweder *et al.*, 1992; 1993) suggests that correction for animals missed is more important for minke whales than fin whales.

Little is known about humpback whale distribution and abundance in the Bering Sea (Perry *et al.*, 1999). Our estimate of 1,175 whales (95% CI = 197-7,009), despite the associated large uncertainty, indicates that humpback whales clearly use the Bering Sea as a summer feeding ground. As for minke whales, there are records of humpback aggregations along the Chukotka Peninsula (e.g. Melnikov *et al.*, 1999), so clearly the estimate here does not account for all humpbacks in the Bering Sea. Whaling records show that in the Bering Sea humpbacks were caught, mostly north of Unimak Pass (Reeves *et al.*, 1985), where sightings were clustered during our survey. Notably, humpback whales were not seen in the highly productive areas along the shelf edge where fin whales were found, suggesting temporal or spatial separation in foraging or differences in foraging threshold (Piatt and Methven, 1992) between the two species. It is not clear whether Bering Sea humpback whales all return to the same wintering grounds. Marking studies conducted during years of whaling found humpback whales marked in the Bering Sea moved between both Japanese waters and eastern North Pacific waters (Ohsumi and Masaki, 1975). Thus, more than one stock of humpback whales may be represented in the Bering Sea.

The only North Pacific right whales seen were observed in the eastern Bering Sea, near the location where they have been seen each summer since 1996 (Goddard and Rugh, 1998). As in 1997, the right whales were seen within a coccolithophore bloom (Tynan, 1999). Photographs taken of right whales in 1997 also show 'rust-coloured' callosities, similar to those photographed in 1999. A speculative explanation for the atypical callosity coloration might be a lack of diatoms in the coccolithophore bloom, which may somehow effect callosity coloration.

The opportunistic survey aboard the NOAA ship *Miller Freeman* provided a snapshot of fundamental information about mysticete whale populations in the central Bering Sea. It appears that substantial numbers of fin whales, minke whales and humpback whales occur there, and that they occupy somewhat dissimilar habitats. These preliminary abundance estimates provide a baseline for comparison to data it is hoped will be obtained in subsequent surveys. Finally, the observation of North Pacific right whales adds to the increasing information base regarding their behavioural ecology in the Bering Sea.

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