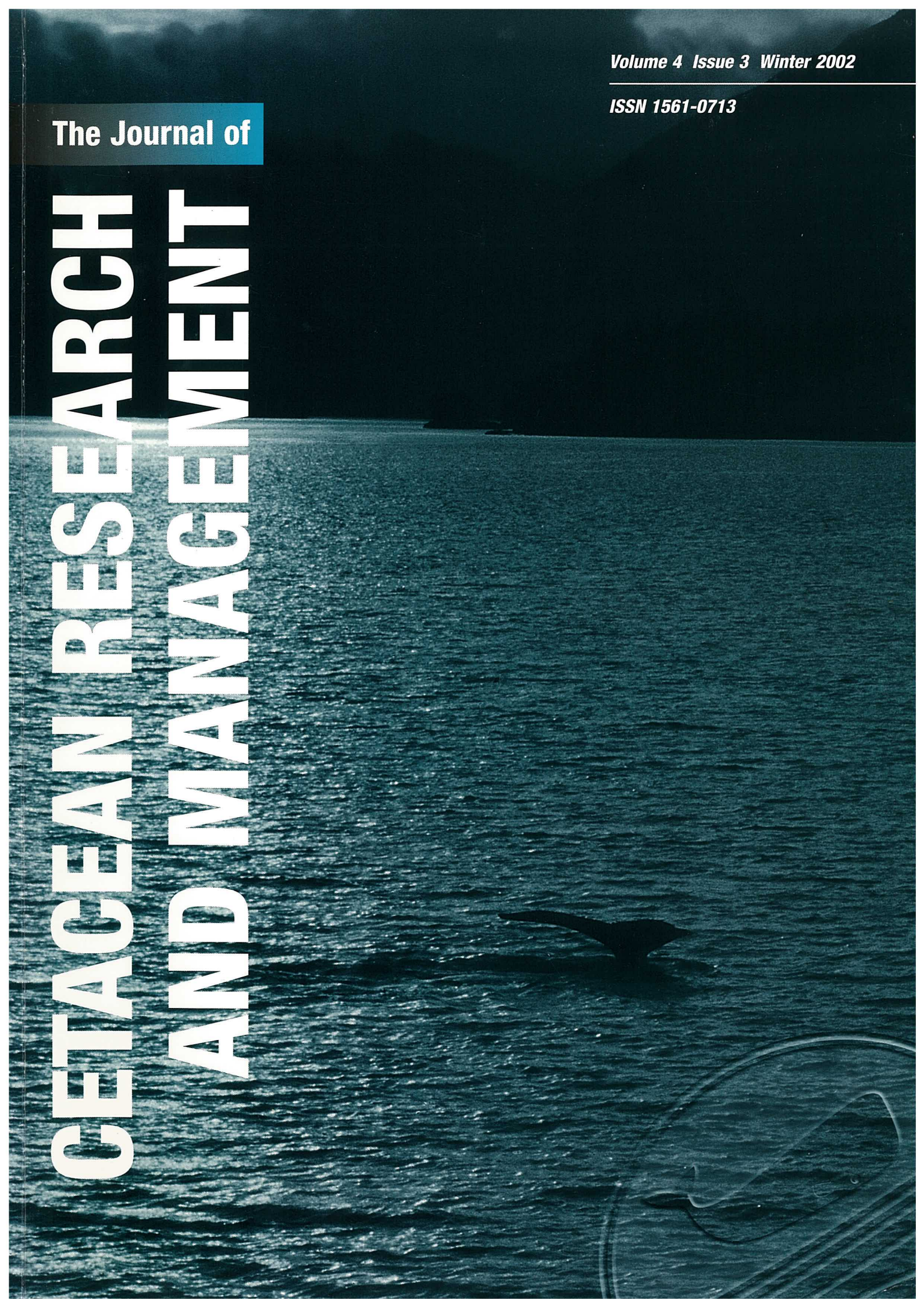


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Editorial

Welcome to the final issue of the fourth volume of the *Journal of Cetacean Research and Management*. Year 2002 has been another good year for the Journal. A total of 37 papers have been published involving some 114 authors from 21 countries (including from Europe, Africa, Asia, Australasia, North America and South America). I am particularly pleased at the wide geographic spread and range of disciplines included. The published papers illustrate that the *Journal* is fulfilling its aim of improving conservation science in general and in particular the conservation and management of cetaceans throughout the world. An index to Volume 4 appears at the end of this issue.

The present issue again covers a broad range of subjects, areas and species. Three of the papers (two by Reeves *et al.* and one by Kato and Kasuya) show how careful analyses of historical whaling records, whilst fascinating in their own right, can contribute to the determination of the status of present day populations and hence better management. Reeves *et al.* examine issues related to North Atlantic humpback whales in terms of historical catches and distribution, whilst Kato and Kasuya examine similar data for the western North Pacific stock of gray whales, one of the most endangered in the world. Another highly endangered population is the North Pacific right whale – McDonald and Moore present the first good information on calls made from these animals in the eastern Bering Sea. Acoustic data of various kinds are becoming increasingly valuable in conservation related studies.

Photo-identification data form the focus of two papers. Garrigue *et al.* examine the movements of humpback whales throughout the Oceania region of the South Pacific based on collaborative studies. Such work is vital to a better understanding of the stock structure of these animals, an essential component of management and conservation. Calambokidis *et al.* examine the movements of a proposed feeding aggregation of gray whales to try to provide insight on whether they should be managed as a separate management unit from the main western North Pacific gray whale population.

Baird *et al.* look at the potential effect of incidental catches of gray whales on the same population. Whilst such

catches do not pose a threat to this particular population, incidental catches represent the major threat to many cetacean populations around the world. The best way to obtain reliable information on incidental catch numbers is using well-designed independent observer studies. Ferrero *et al.* show how additional valuable data can be obtained from such programmes as they examine small cetacean habitat use in the central North Pacific. In addition to good information on numbers of incidentally caught animals, knowledge of stock structure (and associated population size) is essential to assess the potential impact of such catches. McLellan *et al.* examine long-term strandings information from the eastern USA in the context of current hypotheses of the stock structure of bottlenose dolphins.

Whalewatching is becoming an increasingly popular activity and it is important that it is carefully monitored in order to ensure that any interference does not become a threat to cetacean populations. Williams *et al.* present a study of one particular type of whalewatching practice on male killer whales off British Columbia that may be problematic.

Directed population abundance studies are expensive undertakings and in some areas and countries are not practical for this reason. Pinedo *et al.* examine the potential for platform of opportunity studies to provide abundance and distribution information with reference to studies undertaken off the southern coast of Brazil.

The quality of any Journal is a reflection of the quality and dedication of its reviewers. I would like to thank publicly here all those scientists who dedicate a considerable period of time to offering constructive and valuable criticism and advice on submitted manuscripts. This not only ensures the high quality of published papers but also serves to improve the quality of cetacean management science throughout the world. An updated list of referees can be found on the journal website (<http://www.iwcoffice.org/Publications/reviewers.htm>).

G.P Donovan
Editor

Historical catches of humpback whales in the North Atlantic Ocean: an overview of sources

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ABSTRACT

Humpback whales (*Megaptera novaeangliae*) have been taken in the North Atlantic since the 1600s in a variety of fisheries operating from the Arctic to the tropics. The relative importance of the humpback whale in these fisheries has varied. In some it was the main target species, while in others it was a minor component of the catch, with other large rorquals or sperm whales (*Physeter macrocephalus*) ranking ahead of it. There was an overall trend towards large catches of humpback whales, especially in tropical breeding areas, by non-mechanised fisheries during the mid to late 19th century; as these fisheries declined and modern whaling began in higher latitudes, large numbers were taken on the feeding grounds. Catches generally declined in the mid to late 20th century, with many fisheries stopping or scaling down their operations. Information describing the humpback fisheries is published in a wide variety of sources, and approximate locations and periods of operation are reasonably well known for most of the relevant fisheries. In addition, catch and production data are available in commercial records, newspapers and whaling manuscripts (e.g. voyage logbooks). This paper summarises the data sources and defines thirteen 'fisheries', based mainly on the whaling methods employed, and 20 'sub-fisheries', based mainly on the spatial distribution of the whaling operations. Catch levels are summarised, often crudely, and gaps in the catch history are identified. Where possible, suggestions are made for filling these gaps.

KEYWORDS: HUMPBACK WHALE; WHALING–HISTORICAL; NORTH ATLANTIC OCEAN; CATCH LEVELS

INTRODUCTION

Humpback whales (*Megaptera novaeangliae*) were hunted in the North Atlantic Ocean from the early 17th century or earlier. The catch history is reasonably complete for most of the 20th century but fragmented and incomplete for earlier times. Mitchell and Reeves (1983) provided an extensive account of the history of whaling for this species in the western North Atlantic, primarily a review of literature supplemented by unpublished data from a sample of American whaling logbooks and journals from the Providence Public Library (Rhode Island) and New Bedford Whaling Museum (Massachusetts). They emphasised the years 1850–1971 but cited numerous references to humpback whaling prior to 1850. These authors recognised the incompleteness of their study and recommended further historical research focussed on, for example: (1) Blue Books and other export or tax records from the West Indies and Bermuda; (2) Danish colonial records from shore stations in West Greenland; (3) improved documentation from Iceland (see their Endnote 3); and (4) American whaling logbooks covering voyages to the Cape Verde Islands, a humpback wintering area. Considerable progress has been made since 1983, stimulated in part by the need for complete catch series to assess the present status of humpback whales in the North Atlantic (IWC, 2002a, pp.39–44).

The whaling operations that exploited humpback whales in the North Atlantic were extremely diverse both spatially and temporally (Mitchell and Reeves, 1983). They also differed in terms of the killing and processing methods, vessel propulsion (hand, sail, steam, gas engine), whether they were pelagic or shore-based and the degree to which they focussed on the humpback or other whale species. This paper summarises the available evidence for humpback whaling in various parts of the North Atlantic and assesses the degree to which catch series are representative or complete. It defines distinct fisheries and sub-fisheries based

on whether the operations were pelagic or land-based, and non-mechanised (e.g. sail power and hand-thrown, non-explosive harpoons) or mechanised (e.g. engine-powered vessels and gun-launched, explosive harpoons). The scale of humpback catches in each of the fisheries and sub-fisheries is estimated, the usefulness of various sources is evaluated and areas and times that need further investigation are identified.

IWC (2002b) used the sources cited in the present paper as the basis for developing a time series of removals of humpback whales throughout the North Atlantic as part of its work to assess the status of this species in the region. In addition, it used the new data on Barbados whaling (Table 2, see later) to estimate catches for that island fishery during the 19th and early 20th centuries.

OVERVIEW OF FISHERIES

Thirteen fisheries were defined and three of these were sub-divided into a total of 20 regional sub-fisheries. The suggested names for the fisheries are based on nationality or region, the degree of mechanisation (referring mainly to involvement of explosives and engine power) and whether operations were pelagic or shore-based (Table 1). The American Non-mechanised Pelagic fishery, often referred to as 'Yankee whaling', included two well-defined sub-fisheries, one in the West Indies and one in the Cape Verde Islands. A third sub-fishery was defined as encompassing opportunistic takes of humpback whales elsewhere in the North Atlantic. The West Indies Non-mechanised Shore fishery was broken down into six local sub-fisheries based in as many islands or island groups. The modern whaling methods used in the Norwegian Mechanised Shore fishery were developed late in the 19th century and eventually applied in many parts of the North Atlantic. At least 11 of this fishery's local or regional

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sub-fisheries reported humpback landings, ranging latitudinally from as far north as Svalbard to as far south as Grenada. Some of the sub-fisheries of the Norwegian Mechanised Shore fishery were short-lived and some appear to have taken only a few humpback whales.

In the following section, the sources of information are summarised for each of the fisheries and sub-fisheries.

NORWEGIAN MECHANISED SHORE WHALING

North and West Norway

Humpback whales are not known to have been hunted regularly in Norwegian waters prior to the development of transitional and modern whaling techniques. Experimental whalers operated in the Norwegian and Barents Seas from the 1850s-1870s. For example, Thomas Welcome Roys shot 26 humpback whales in the Barents Sea in the summer of 1856, killing at least 16 of them (Schmitt *et al.*, 1980; Tønnessen and Johnsen, 1982). Roys' Norwegian contemporaries, including Svend Foyn, used Varanger Fjord, Finnmark, as their base of operations beginning as early as 1857. Although it has often been stated or implied that these whalers took only blue whales (*Balaenoptera musculus*) prior to 1883, humpback and other whales were taken as well (Tønnessen and Johnsen, 1982).

As defined here, the North Norway sub-fishery encompasses the shore-based whaling in east and west Finnmark and along the Murman coast of Russia. Whaling in the latter area involved 'state-subsidised catching in the Barents Sea off the coast of Murmansk' and lasted only from 1883-89 (Tønnessen and Johnsen, 1982). Of 292 whales taken off Murmansk from 1885-87, only 25 were humpback whales (Jonsgård, 1977).

The whaling industry in Finnmark expanded dramatically in 1883 when the number of shore stations increased from seven to 16; and the number of catcher boats, from 15 to 27 (Jonsgård, 1977). It is likely that some of the 1,026 'unspecified' whales taken in 1883-84 were humpback whales. Ingebrigtsen (1929) cited Risting (1922) for a catch of 1,064 humpback whales off Finnmark from 1885-1904 and reasoned that since some of the unspecified whales reported in the catches during this period were probably humpback whales, the actual total for Finnmark and Bear Island was 'not more than' 1,500, by which he seems to have meant about 1,500. Jonsgård (1977) listed 1,075 humpback whales taken in North Norway from 1885-1904 as well as 4,511 'unspecified' whales between 1891-95, some of which must have been humpback whales. Whales taken near Bear Island during 1903-04 were towed to Finnmark for processing and therefore would have been reported in the North Norway catch (Tønnessen and Johnsen, 1982, p.49). Catches in North Norway and West Norway after 1904 were comparatively small (Jonsgård, 1977).

Svalbard

Modern shore whaling, which involved the use of land stations as well as some of the earliest floating factories, began at Svalbard in 1903 and continued sporadically until 1927, with a total reported humpback catch of 42 (Jonsgård, 1977; Tønnessen and Johnsen, 1982). Some of the 461 'unspecified' whales reported from 1906-12 (Jonsgård, 1977) also could have been humpback whales. Catches delivered to a shore station established at Bear Island in 1905 (Tønnessen and Johnsen, 1982, p.98) presumably were reported in the statistics for Svalbard.

Iceland

Mitchell and Reeves (1983) estimated that at least 26 humpback whales were killed by experimental whalers off Iceland in 1865-66 based on a known catch of 13. They doubled the known catch to estimate the total kill based on comments in the literature referring to very high loss rates. No estimates were included in their Table 1 for the years 1863-64 and 1867-72 even though they stated that the experimental whalers targeted some humpback whales around Iceland during these years.

Modern whaling was introduced to Iceland by Norwegian whalers in 1883 (Sigurjónsson, 1988). Seven stations operated on the west coast until about 1900 and five on the east coast from then until about 1915. Ingebrigtsen (1929) guessed that about 1,500 humpback whales were taken from the 1880s to early 1900s. Mitchell and Reeves (1983) listed a total catch of 902 between 1889-1915 based on data from Jonsgård (1977) for the years 1883-97 and 1903 onwards and pro-rating his data for 1898-02 on the basis of a statement in Risting (1931). Sigurjónsson (1988) estimated a total secured catch of 2,800 humpback whales by Icelandic shore whaling from 1889-1915, more than three times the estimate by Mitchell and Reeves (1983). Sigurjónsson's estimate is likely to be more accurate because he had access to data unavailable to Mitchell and Reeves.

Faroe Islands

Degerbøl (1940) summarised catch data from shore stations in the Faroe Islands between 1894-1939. The data for 1894-1902 were entirely unspecified and, in addition, a variable proportion of the catch remained unspecified until the 1930s. As in Iceland, in the early 'unspecified' years of the fishery, catches probably were of blue and humpback whales. Degerbøl implied that a large proportion of the 1,215 whales taken from 1894-1902 were these two species and that their local availability had already decreased by 1903 when, for the first time, a portion of the catch was specified. He listed a total of 189 humpback whales secured between 1903-30 and another nine between 1935-39. The sex ratio ($n = 149$) was about 1.5, favouring males. Animals ranged in body length from 33-50 Danish feet (*ca* 10.36-15.69m) and the peak months for catching humpback whales were July and August. Jonsgård (1977) indicated that only nine additional humpback whales were taken at the Faroes after World War II.

British Isles

Humpback whales were rarely taken at modern shore stations in the Shetland Islands between 1903-29 (total of 51; Brown, S.G., 1976; also see Thompson, 1928), the Outer Hebrides between 1904-28 (total of 19; Brown, S.G., 1976) and Ireland between 1908-14 (total of 6; Fairley, 1981). July and August were the peak months of occurrence off Scotland; the catch was mostly males; and the most productive area for catching humpback whales was to the north of Shetland and Rona (Thompson, 1928).

Newfoundland

Based on searches of Newfoundland newspapers and archives, Sanger and Dickinson (1989) confirmed that the Mitchell and Reeves (1983) estimate of 15 humpback whales killed at Newfoundland in 1898 was too low. Moreover, Dickinson and Sanger (1990) called attention to a miscalculation that led Mitchell and Reeves (1983) to overestimate the 1901 humpback kill, which was ten (seven at Balaena, two at Chaleur Bay, plus one to account for sinking loss) rather than 18. Further studies of primary

Table 1

North Atlantic whale fisheries in which humpback whales were taken, showing sub-fisheries, their total periods of operation (not necessarily continuous) and cumulative takes of humpback whales (unadjusted for hunting loss). Fisheries and sub-fisheries are defined according to whether they involved land stations or pelagic operations, technology used ('transitional' is indicated separately) and geographic area. Specific areas where humpbacks were caught are listed.

Fisheries	Sub-fisheries	Periods	Transitional	Humpbacks taken ¹	Humpbacks among principal target species?	Areas where humpbacks taken	
Norwegian mechanised shore	N. Norway	1868-1971	No	1,146 reported; possibly 100s more unspecified	Early yes, late no	Including Murman Coast	
	W. Norway	1912-69	No	43 reported	No		
	Svalbard	1903-27	No	42 reported; probably a few more unspecified	No		
	Iceland	1883-1989	No	219 reported; 2,800 estimated before 1915	Early yes, late no		
	Faroes	1894-1984	No	189 reported; at least several 100s more unspecified	Early possibly yes, late no		
	British Isles	1903-51	No	65 reported; probably a few more unspecified	No		Shetlands, Hebrides, Ireland
	Newfoundland	1898-1971	No	1,216 reported; at least 10s more unspecified	Early yes, late no		Including Strait of Belle Isle and Labrador
	Gulf of St Lawrence	1911-15	No	3 reported	No		
	Nova Scotia	1964-71	No	7 reported	No		
	Grenada	1925-26	No	174 reported	Yes		
Norwegian mechanised pelagic	Spain-Portugal	1921-85	No	3 reported	No	NW Spain	
		1911-37	No	451 reported; probably at least 10s more unreported	Early yes, late no	Davis Strait, Denmark Strait, Iceland, Bear I., Spitsbergen	
Greenland non-mechanised shore		1700s-1923	Yes?	<20/yr, possibly low 1,000s all told	Yes		
Greenland mechanised shore		1924-present	No	>300 reported	Yes		
Canada non-mechanised shore		Late 1700s-mid 1800s	No	?	Possibly	Newfoundland, Gulf of St Lawrence	
Canada non-mechanised pelagic (Gaspé)		1804-93	Yes	100s to low 1,000s	Yes	Newfoundland, Labrador, Gulf of St Lawrence	
American non-mechanised coastal		Early 1700s-mid 1800s	Yes	Probably 100s	Probably	Nantucket, New York, North Carolina	
American mechanised coastal		ca 1850-1895	Yes	Probably 100s	Yes	Gulf of Maine	
Bermuda non-mechanised shore		1600s-1941	Yes	At least 100s	Yes		
West Indies non-mechanised shore	Barbados	1868-1913	?	100s	Yes		
	St Vincent and the Grenadines	1876-present	Yes	Low 1,000s	Yes	Bequia, Frigate Rock, Canouan, Palm Island	
	Grenada	Early 1900s-1924	?	14-18 reported; probably at least 10s more	Yes	Glover Island, Isle de Caille, St George's	
	Trinidad	1826-1870s	No	Several 100s	Yes		
	St Lucia	Late 1800s-early 1900s?	?	?	?		
	Turks and Caicos	~1880s	?	?	?		
	American non-mechanised pelagic	West Indies	1772-early 1900s	Yes	1,000s	Yes	Hispaniola to Venezuela, especially Lesser Antilles
Cape Verde Is		Ca 1785-1901	Yes	High 100s to low 1,000s	Yes	Cape Verde Is, esp. Sal, São Nicolau and Boa Vista	
Other Areas		1730s-late 1800s	Yes	Probably at least 100s	Early yes, late no	Newfoundland, Gulf of St Lawrence, Davis Strait	
Cape Verde Islands non-mechanised shore		Late 18 th century-1912	No	Probably at least 100s	Probably	Brava, São Nicolau, Sal, Maio	
Madeira non-mechanised shore		1941-81	No	5 reported	No		

¹ 'Reported' indicates an exact cumulative total obtained from Bureau of International Whaling Statistics or a published source; other, less precise values refer to cumulative estimates for the entire period of the fishery's operation. Reported values are negatively biased in some instances by the fact that an unknown proportion of the 'unspecified' whales landed were humpbacks.

materials in Newfoundland and Labrador (Sanger and Dickinson, 1995; Dickinson and Sanger, 1999) provide no basis for changing the 20th century estimates by Mitchell and Reeves (1983), which included 34 whales taken in 1969-71 under a special scientific permit (Mitchell, 1973).

Gulf of St Lawrence

A brief episode of modern whaling at Seven Islands (Sept-Îles) on the north shore of the Gulf of St Lawrence took mainly blue and fin whales although in most years the catch was unspecified. At least 659 whales were taken between 1905-15, possibly including at least three humpback whales in 1911 (Mitchell and Reeves, 1983).

Nova Scotia

A whaling station at Blandford, Nova Scotia, operated from 1964-71 and took seven humpback whales under a scientific permit in 1969-71 (Mitchell, 1973).

Grenada

A modern whaling station was established on Glover Island in 1924 and began operations in 1925 (not January 1924 as indicated by Mitchell and Reeves, 1983; see Romero and Hayford, 2000). It lasted for only two years, taking 174 humpback whales, about 80% of them males (Mitchell and Reeves, 1983).

Spain – Portugal

Modern whaling on the Iberian Peninsula began in 1921 and continued until 1985 (Sanpera and Aguilar, 1992). Only two humpback whales were reported in the catches. Two more were taken by the 'pirate' whaler *Sierra* in December 1978, possibly in waters off the Iberian Peninsula or northwestern Africa (Sanpera and Aguilar, 1992).

NORWEGIAN MECHANISED PELAGIC WHALING

Modern whaling vessels from Norway, primarily associated with floating factories, took humpback whales in the North Atlantic between 1911-37. Mitchell and Reeves (1983) were interested only in the catches made in Davis Strait (i.e. the 'western North Atlantic'). These were presented in their table 1 with a loss rate factor of 1.06 applied. Norwegian vessels also took this species in Denmark Strait/Iceland and Bear Island/Spitsbergen. The catches from 1929-37 were attributed by Jonsgård (1977) and the Bureau of International Whaling Statistics to the 'Arctic' or 'North Atlantic'. Jonsgård provided Mitchell and Reeves (1983) with information from nine of 14 expedition logbooks, allowing them to assign 34 humpback whales taken between 1930-34 to Davis Strait, eight to Denmark Strait/Iceland and 37 to Bear Island/Spitsbergen.

GREENLAND: NON-MECHANISED SHORE WHALING

A shore-based fishery for humpback whales was already 'well-developed' in West Greenland by the late 1700s (Mitchell and Reeves, 1983). They were known to be taken at least occasionally by non-mechanised commercial whalers in Davis Strait (e.g. 15 by one British vessel in Disko Bay in one season between 1840-58). Nevertheless, table 1

in Mitchell and Reeves (1983) listed no catches in this area until 1866, and catches for non-mechanised and mechanised shore whaling in Greenland were combined within a single column of that table. For the Greenland shore-based hunt, Mitchell and Reeves arbitrarily assigned a value of four killed whales/year from 1866-85 based on statements in the literature (Rink, 1877) that an average of no more than two whales were secured per year and that killed whales were often lost (a loss rate factor of 2.0 was applied). It was noted that single-season catches had been as high as 13 (at Frederikshåb [Paamiut] in 1844) and possibly 22 (some time before 1841) in earlier years and that by 1877 the West Greenland humpback fishery was in decline. For 1886-1923 Mitchell and Reeves (1983) used the catches listed by Kapel (1979) multiplied by 1.5 to account for hunting loss. They considered Kapel's (1979) catch records incomplete and noted that 19th century catches were probably 'somewhat higher' than indicated in their table.

GREENLAND: MECHANISED SHORE WHALING

Mechanised whaling was introduced to West Greenland in 1924 when the catcher boat *S/S Sonja* began whaling to supply an oil plant in Copenhagen as well as provide food for Greenlanders and their dogs (Kapel, 1979). The West Greenland catches listed by Mitchell and Reeves (1983) for 1924-71 came from Kapel's (1979) tables. The numbers were not adjusted for hunting loss, although inexplicably Mitchell and Reeves listed the catch as one whale greater than the corresponding figures in Kapel's table 1B for the years 1924 and 1926-29.

CANADA: NON-MECHANISED SHORE WHALING

Large quantities of oil were exported to the United Kingdom from Newfoundland between 1696-1734. Reeves *et al.* (1999) argued that much of this production apparently was from seals. However, the occasional inclusion of whalebone (baleen) indicates that some of the oil was from mysticete whales. There was no basis for determining what proportion of it might have come from humpback whales.

Mitchell and Reeves (1983) were unable to confirm that there was any shore-based whaling for this species in eastern Canadian waters prior to 1898. They attributed most of the whaling in bays along the south and east coasts of Newfoundland and in the Strait of Belle Isle and Gulf of St Lawrence to pelagic whalers from either New England (see below) or the Gaspé Peninsula in Quebec (see below). Some humpback whales probably were included in the sporadic and poorly documented shore whaling operations in Newfoundland and Labrador but these could not be quantified from available evidence. References to a subsidy ('bounty') offered by the government of Newfoundland to encourage whaling out of St John's in 1840, and to single-season catches of up to 100 whales (apparently in the Gulf of St Lawrence), indicate considerable whaling activity at that time.

CANADA: NON-MECHANISED PELAGIC WHALING

A separate fishery for large whales existed in the Gulf of St Lawrence between 1804-93, involving as many as ten schooners in the peak years, all based on Quebec's Gaspé Peninsula (Mitchell and Reeves, 1983). Although North Atlantic right whales (*Eubalaena glacialis*) would have been welcome targets, their relatively low abundance from the

earliest years of this fishery meant that other species, probably primarily humpback whales, were the main targets. Although contemporaneous with the American and British pelagic whale fisheries, this Gaspé fishery appears to have been independent of and competitive with them.

Mitchell and Reeves (1983) produced a series of removal estimates for the Gaspé fishery for the years 1858-88. They assumed, based on published narratives describing the fishery, that humpback whales comprised half of the reported catch. Oil returns were converted to whales using average yields of 50bbl or 1,500gal¹. For the five years with no data, they interpolated to estimate production using the midpoint of the oil returns in the immediately preceding and succeeding years. The little information available on loss rates in this fishery was deemed 'equivocal' and Mitchell and Reeves (1983) somewhat arbitrarily applied a loss rate factor of 1.2.

In table 1 of Mitchell and Reeves (1983), a guess of five whales killed per year was assigned to the period 1850-52. For the period 1853-57 they assumed a constant production level of 750bbl of oil/year (from McDougall, 1979), equivalent to nine humpback whales killed/year based on the reasoning outlined in the foregoing paragraph. For the years 1858-88, the loss-adjusted estimates from Mitchell and Reeves (1983) were used (note, however, that the catch of 14 attributed to 1888 was a transcription error and should have been four). No indication was given of catches from 1889-93 although some whaling apparently occurred in those years.

AMERICAN NON-MECHANISED COASTAL WHALING

References to humpback whaling at Nantucket and elsewhere in New England during the 1700s and 1800s, with few details, were summarised by Mitchell and Reeves (1983). Little (1988) interpreted data in a Nantucket account book for 1721-58 to mean that most of the catch consisted of either right whales or sperm whales (*Physeter macrocephalus*): 'Some humpback whales or blackfish may have been included in the catches, but were not the primary objectives of Nantucket whalers'. The whaling grounds used by the Nantucket whalers during this period included 'along-shore' at Nantucket, the nearby 'Bowbell', 'ye deep' offshore of the island, 'Cariliner' (North Carolina), 'Canso' (the Strait of Canso, separating Cape Breton Island from mainland Nova Scotia), 'Newfoundland' and 'Greenland'. Humpback whales could have been taken in any of these areas and apparently some voyages targeted them explicitly. For example, a logbook entry of the sloop *Seaflower* in 1752 reads: 'We Shall Have a good time to Newfoundland to kill Some Humps' (Reeves and Mitchell, 1986a). Macy (1835), in describing the disastrous impact of the War of Independence (1775-1783) on the Nantucket whaling fleet, noted that 'Humpback whales ... and cod fish were plenty' on the Nantucket Shoals to the east of the island, thus giving 'encouragement to many, who would otherwise have been idle, to engage in the pursuit of them'. The implication was that during the mid-1770s at least, considerable effort was directed at killing humpback whales in local waters. No quantitative documentation was available, however, on either the effort or the take. This focus on nearby humpback

whales could not have lasted for long. Soon after hostilities began, most Nantucket whalers either lost their vessels or relocated so that they could operate in the South Atlantic (Stackpole, 1972).

A whale fishery based at Prospect Harbor, Maine, existed from about 1810-60 (Clark, 1887). Initially the whales were spotted from a shore lookout but by the 1820s, the whalers had acquired large enough boats to allow them to search farther away from the coast. It is likely that this fishery was mainly for humpback whales given that: (a) the average oil yield was 25-30 bbl²; (b) there is no indication that whalebone was a product; and (c) the technology for catching fin whales was not yet available (see below). Also, the whales were described as coming near shore, following menhaden (*Brevoortia* sp.), about 1 June and remaining until September. The average annual catch from 1835-40, when this fishery was at its peak, was 6-7 whales, with a highest one-year catch of ten. An apparently separate, smaller operation based at Tremont, Maine, from about 1840-60 took at least three whales annually (Clark, 1887). No direct information was available on the species hunted. In 1845 a schooner (*Huzza*) cruised somewhere along the Maine coast, possibly in the general vicinity of Winter Harbor, taking seven humpback whales and one fin whale (Clark, 1887). A mounted skeleton exhibited in Boston that year was probably of a whale taken by the *Huzza* in July (Allen, 1916). According to Clark's informant, the *Huzza's* captain did not continue his operation in subsequent years but went whaling in a different vessel from Prospect Harbor in 1870, securing one fin whale.

Shore whaling was also conducted at various points along the Massachusetts coast during the first half of the 19th century (Webb, 2001; Reeves *et al.*, 2002). The whalers at Provincetown, in particular, 'frequently captured a large number [of whales] in a season' (Clark, 1887). Some of these certainly were North Atlantic right whales (*cf.* Reeves *et al.*, 1999) but some, and possibly most by that time (right whales were badly depleted locally), probably were humpback whales. For example, in 1849 the schooner *Council* of Provincetown obtained 130-160bbl of humpback oil on a cruise between Provincetown and Mt Desert Island, Maine; in 1850 the same vessel took at least one whale in Cape Cod Bay on 31 October and continued whaling until 22 November, returning with 90bbl of humpback oil all told (Wood, no date). In early November 1861, a whale that appeared in the midst of a fleet of 200 mackerel fishing vessels off Nauset, Massachusetts, was taken by a Nantucket fisherman. It was his fifth whale since 15 July and was expected to produce 25bbl of oil. His total return from the five whales was given as 125bbl, worth \$1,500 (Clark, 1887:41). The average yield of 25bbl fits the humpback and the lack of any mention of whalebone implies that none of these were right whales.

A significant transition in whaling technology took place at mid-century. The first bomb lance became available in the United States in 1846 and it was substantially improved in 1852. From that time, the bomb lance was considered to have 'in part revolutionised the process' of killing whales (Brown, J.T., 1887). The widespread use of bomb lances in American whaling clearly expanded the range of species that could be hunted and increased the loss rate. Although it has been

¹ Mitchell and Reeves (1983) considered their estimates 'so crude that it does not matter if these are Imperial or American gallons'. The use of 50bbl as an average yield on this ground, rather than the 25bbl used to estimate breeding ground catches (see Footnote 2, later), was based on those authors' expressed preference for 'conservative' (i.e. negatively biased) catch estimates and a reference in the literature to humpback whales in the Gulf of St Lawrence yielding 10-80bbl.

² Mitchell and Reeves (1983) estimated that humpback whales in the West Indies produced an average of 25bbl of oil. They used this value to convert production data in some, but not all, of the fisheries examined. Best (1987), using a much larger sample of catches by American pelagic 19th century whalers, estimated the average yield from humpback whales to be 24.4bbl (CV = 0.10). The barrel used in those studies contained 31.5 US gal, or 26.28 imp. gal.

assumed that the whaling described in this section was 'non-mechanised' and 'coastal', some catches in the mid-19th century could have been made from schooners using explosive projectiles.

Shore whalers at Long Island, New York, killed a humpback whale in 1852 (Reeves and Mitchell, 1986b). Although shore whaling was practised along the southeastern coast of the United States from the late 1600s to early 1900s, there is no suggestion that humpback whales were taken there regularly (Reeves and Mitchell, 1988). Simpson and Simpson (1988) quoted a 19th century source who was told by whalers on Shackleford Banks, North Carolina, that in addition to right whales, they occasionally took humpback and possibly gray ('scrag') whales (Mead and Mitchell, 1984).

AMERICAN MECHANISED COASTAL WHALING

This fishery is not easily defined but was generally characterised by the use of steam vessels and/or explosive projectiles (although not necessarily deck-mounted). The data for this transitional fishery tabulated by Mitchell and Reeves (1983) were only illustrative. Estimated kills for some years (their table 1) were based on the assumption of an average oil yield of 25bbl/whale and it was assumed that only half of the humpback whales killed or mortally wounded were secured (loss rate factor of 2.0). Because of the non-systematic nature of reporting and the incompleteness of their literature and archival search, the estimates given by Mitchell and Reeves (1983) must have been negatively biased to a considerable degree.

During the late 1870s and early 1880s, there was a flurry of interest in catching rorquals off the New England coast. In 1879, a small Provincetown schooner, the *Brilliant*, humpbacked off Deer Isle, Maine, securing four whales producing 155bbl of oil by the end of September (Clark, 1887; Webb, 2001). This vessel carried only one whale boat and the whales were towed ashore for flensing. No information was available on catches by other vessels engaged in this fishery at the time although Clark's characterisation of the *Brilliant* as 'one of the most successful whalers out of Provincetown that season' implies that at least a few other whales were taken. In 1880, 48 whales, all or most of them fin whales, were taken at Provincetown yielding 29,925gal of oil and 8,750lb of bone (baleen) (Clark, 1887). These products (at \$0.40/gal for oil and \$0.15/lb for bone), together with the proceeds of two whales sold for exhibition in Boston and New York, were valued at \$14,037. No information was available on how many vessels were involved.

The loss rate in this fishery was very high. Bomb lances were used to kill the whales, which typically sank for two or three days before being towed to shore for processing. One whaler noted that approximately as many whales were killed and lost as were finally secured for processing (Clark, 1887). In 1880, six fin whales that had been killed by the Provincetown whalers were later found floating in Massachusetts Bay and towed into Gloucester harbour. Three more were taken into Boston, one to Newburyport, one to Cape Porpoise, one to Portland and one to Mt Desert. Two more drifted ashore at Scituate, two at Barnstable, one at Brewster, one at Orleans, two at Wellfleet and one on 'the back of Cape Cod'. Another was found and flensed at sea by a fishing vessel and its blubber sold in Boston (Clark, 1887). Of some 100 whales estimated to have been killed by Provincetown whalers that season, only three were said to have been humpback whales, the rest fin whales (Clark,

1887). In the same year, a whale (species unspecified) was killed and tried out at Bass Harbour, Maine (Clark, 1887). The fact that it yielded only 1,200gal of oil and no bone suggests that it was not a right whale but rather a humpback or fin whale.

A Boston newspaper account published in 1881 claimed that it was only 'within the past three years' that a 'home whale-fishery' had been prosecuted at Provincetown (Clark, 1887). Participants were said to be mainly younger men as the older whalers in the area had too low a regard for fin whales to engage in their pursuit. One young captain was said to have taken at least 250bbl of oil in 1880 in and around Cape Cod Bay and he was 'scoring fair results' in 1881, having obtained 90bbl of oil in Massachusetts Bay well before the end of the season. He was cruising off Grand Manan Island in the lower Bay of Fundy 'with a better Provincetown schooner than he had last year'; this vessel was likely the same schooner that took 100-150bbl of 'humpback oil' on the Maine coast (Clark, 1887; also see Reeves and Barto, 1985). However, as of November 1881 only 'a few' whales had been taken in Provincetown harbour. According to an article from the *Oil, Paint, and Drug Reporter* of 23 November 1881, quoted in Clark (1887), no other vessels took up this hunt in 1881 although a 'menhaden steamer' had cruised near Block Island 'without making a haul' (i.e. without catching any whales?). Additional information on this fishery is available in Webb (2001) and Reeves *et al.* (2002).

Reports vary as to the species composition of the catches but fin whales appear to have predominated, followed by humpback whales, perhaps with occasional blue and right whales. One newspaper source claimed that a humpback was 'much more valuable than a finback, yielding twice as much of oil for the same size of creature' (Clark, 1887).

Although it was clearly secondary in importance to oil, the baleen was frequently saved and marketed. Apparently the principal use of humpback and fin whale baleen in the 1870s-1880s was in the manufacture of corsets (Clark, 1887). At this time whale oil was used in many industries 'but chiefly by tanners in the preparation of leathers'. It was also used when mixed with lead and paraffin oil for lubricating axles and wheels.

A humpback whale was shot with a 'whale gun' off Long Island, New York, in 1913 but attempts to take the species apparently were exceptional in this area (Reeves and Mitchell, 1986b).

BERMUDA: NON-MECHANISED SHORE WHALING

Bermuda had a long history of shore whaling for humpback whales (Mitchell and Reeves, 1983). The 39 animals listed for 14 years in table 1 of Mitchell and Reeves (1983) certainly under-represent the true numbers killed, particularly prior to the 1880s. Humpback whaling at Bermuda began in the 1600s and continued, at least sporadically, for nearly three centuries.

WEST INDIES: NON-MECHANISED SHORE WHALING

The numerous small-scale whaling establishments in the West Indies, except those in Trinidad (Reeves *et al.*, 2001a), depended on open-boat, hand-harpoon techniques introduced by American pelagic whalers. Shoulder guns were employed regularly and from the early 1920s bomb lances were used as well (Adams, 1971). Like their

American counterparts, the West Indies shore whalers selectively targeted cow and calf pairs. Of 52 humpback whales killed at Bequia between 1950-84, seven were described as solitary males, 25 as mature females and 22 as calves (Price, 1985). Hunting loss was high owing not only to the technology in use, but also to the problem of shark damage to carcasses during towing and flensing (Mitchell and Reeves, 1983).

Barbados

Although one kill was reported in 1813 (Mitchell and Reeves, 1983), shore whaling appears to have been most active at Barbados from 1869-1913. Aspinall (1931) referred to Speightstown as 'the headquarters of a small whaling industry', implying that a station was active there in the 1930s. It is likely, however, that the statement was simply carried forward from an earlier edition of Aspinall's guide book, first published in 1907.

Mitchell and Reeves (1983) estimated removals from 1869-78 based on Archer's (1881) oil-production data, assuming that a tun was equivalent to 252 American gallons, a barrel contained 31.5 American gallons and the average yield of humpback whales in this fishery was 30bbl. Estimates of landings were adjusted for loss using a correction factor of 1.85. For 1879-1902, Mitchell and Reeves simply extrapolated their 1878 estimate of 20 whales, reasoning that Archer (1881) had given no indication of a decline before his catch series ended in 1878, and Brown (1942) had described the fishery as 'at its height' just before the end of the 19th century, with eight boats engaged (Archer's company employed only four). Moreover, Brown claimed that 15-20 humpback whales were caught annually up to 1902. For 1903-13, Mitchell and Reeves inferred an annual kill of six whales based on statements in the literature that although the fishery 'collapsed' around the turn of the century, some effort continued until at least 1913, with four whales secured and two killed but lost by the two boats whaling in 1912 (Sinckler, 1913).

For the present study, all Barbados Blue Books available at the Public Record Office in London were examined for whaling data (Table 2). These indicated that the shore station at Speightstown was established in 1868 or 1869, which is consistent with Archer's (1881) statement that by 1881 he had been whaling in Barbados for 14 years. The Blue Books also confirmed that the fishery continued into the 20th century and reached a peak in both effort and production around the turn of the century. The large amount of oil recorded for 1869 (300 tons) is almost certainly in error as the maximum amount reported by Archer (1881) for any year was 80 tuns in 1871. At least in some years, production data in the Blue Books may refer to amounts exported and therefore not reflect the amounts of oil and meat consumed domestically.

Catches totalling 191 whales from 1921-26 were erroneously listed in the Barbados column of table 1 in Mitchell and Reeves (1983). They should have been listed in the Grenadines column (see Grenada sections, above and below).

St Vincent and The Grenadines

Mitchell and Reeves (1983), following Adams (1971), used the term 'Grenadines' to include the entire island chain from St Vincent to Grenada, inclusive, even though the St Vincent Grenadines and the Grenada Grenadines were administratively (and are now politically) separate, the latter including the islands of Isle de Caille and Carriacou.

Organised shore whaling did not begin in the Grenadines until about 1875-76. It has continued to the present in Bequia but had largely ended in the other islands by the mid-1920s (Adams, 1971; 1975).

The kills attributed by Mitchell and Reeves (1983) to the Grenadines between 1876-1920 consisted of three crude estimates. For the years 1876-79 it was inferred that the small station on Bequia, attended by three or four whaling boats, was the only site in operation (Adams, 1971). The estimated annual kill of seven whales was based on Adams' (1971) statement that the station was 'fortunate to dispatch more than six or seven whales in the season'.

For the entire period 1880-1913 Mitchell and Reeves listed 44 whales killed per year according to the following reasoning: (1) Adams (1971) stated that 'at least a score' of whaling stations, each with three to five whale boats, were established in 'the south Windward Islands and Trinidad' between 1870-1925, of which at least six were still active in the 1910s; (2) Mitchell and Reeves assumed that at least six stations were active at any given time between 1880-1913³; (3) if each of six stations took four humpback whales per year⁴, the total secured catch would have been at least 24 per year; (4) applying a loss rate factor of 1.85 gives the annual kill of 44.

Mitchell and Reeves (1983) inferred from Adams' (1971) account that the local availability of humpback whales around St Vincent (Bequia) was declining from about 1910 onwards, so the annual kill assigned to the years 1914-20 was nine, assuming that only three stations were active and that three whales were killed at each of them. For 1922-78, Mitchell and Reeves (1983) tabulated data from various sources to generate estimates of each year's kill at Bequia. Where only oil data were available they assumed an average yield of 1,000gal/whale (per Adams, 1971). Landings were adjusted for hunting loss using a loss rate factor of 1.5. Adams (1971) explicitly stated that no whales were caught during the period 1949-57.

Mitchell and Reeves (1983) summarised data from the St Vincent colonial Blue Books but did not use them to estimate catches (see their Endnote 1). Generating a catch series from the Blue Book data would require standardisation of the volumetric units in the whale oil column. Conversion to standard units would be straightforward except in the case of casks. Although Mitchell and Reeves considered a cask equivalent to a barrel, ten different types of casks were used in the American whale fishery holding anywhere from 60-290gal (Hohman, 1928; also see Romaine, 1951).

Price (1985) examined St Vincent Blue Books in the Kingstown public library covering 16 years of the 40 years between 1898-1938. He interpolated values for the missing years and attempted to construct a complete catch series for this period using an average oil yield and a loss rate factor from Mitchell and Reeves (1983). The St Vincent Blue Book data from the Public Record Office in London, presented by Mitchell and Reeves (1983), are more detailed and comprehensive, covering all years from 1860-1920. However, Price's data make it possible to extend the St Vincent catch series forward to 1984, i.e. 13 years beyond the last year in Mitchell and Reeves' table 1 and six years beyond the last year in their table 14. IWC (2002b) used all of these data to produce annual catch estimates for this sub-fishery.

³ The 1913 cut-off date apparently was based on Fenger (1913), who noted that at least five stations were active between St Vincent and Grenada when he visited the station at Ile de Caille in ca 1911-12.

⁴ 'In 1900, a Grenadine whaling concern had no difficulty in dispatching four whales per season' (Adams, 1971).

Table 2

Whaling data from Barbados Blue Books, 1868-1911. Note: Blue Books for 1865-67 were examined but contained no relevant data.

Year	Effort	Catch/Oil production	Oil exported (value in £/s./d.)	Other information
1868	-	-	1820gal (Brit. vessels) and 1284gal (foreign vessels) to US; 278gal to Br. Guiana	-
1869	-	300 'Tons' oil	-	'... no fisheries with the exception of a whaling Station at Speights Town'.
1870	-	-	123bbl to Br. Guiana (£153/15/0)	a/a
1871	-	-	-	a/a
1872	-	-	£174 worth to Br. Guiana	a/a
1873	-	-	£108 worth to Br. Guiana	a/a
1874	-	-	£195 worth to Br. Guiana; £170 to 'foreign' West Indies	a/a
1875	-	-	£27 worth to Gr. Brit.; £140 worth to Br. West Indies	a/a
1876	-	-	341½bbl (Brit. vessels) and 27bbl (foreign) vessels to Br. West Indies (altogether worth £1227/12/6)	a/a
1877	-	-	43bbl to Gr. Brit. (£172), 139 to US (£556), 90 to Br. West Indies (£360), 6 to Br. Guiana (£20)	a/a
1878	-	-	684bbl to US (£1795/10), 22 to Br. West Indies (£57/15), 13 to Amer. whale ships (£34/2/6)	a/a
1879	-	8bbl (£21)	8bbl to Gr. Brit. (£21)	a/a
1880	-	[same statement as 1879 is carried forward here]	115bbl to Gr. Brit. (£301/17/6), 10 to Br. Guiana (£26/5), 10 to Br. West Indies (£26/5)	a/a
1881	-	42bbl (£110)	16bbl to Gr. Brit. (£42), 26 to Br. West Indies (£68/5)	Whaling station's location given as Hole-Town rather than Speightstown
1882	-	25bbl (£65/12/6)	25bbl to Br. West Indies (£65/12/6)	a/a
1883	-	-	-	No mention
1884	-	-	-	No mention
1885	-	-	-	No mention
1886	-	68bbl (£118/10)	64bbl to Gr. Brit., 4 to Br. Guiana	Whaling station at Hole-Town
1887	-	24bbl (£51)	24bbl to Gr. Brit.	a/a
1888	-	-	None	'There was no shipment of Whale Oil from Whales caught off the coast'.
1889	-	-	175bbl (£459/7/6)	-
1890	-	240bbl (£630)	240bbl (£630) to Gr. Brit.	'... from Whales caught off the coast of the Island'.
1891	-	74bbl (£194/5)	72bbl to Gr. Brit. (£189), 2 to Br. West Indies (£5/5)	a/a
1892	-	190bbl (£498/0/15)	165bbl to Gr. Brit. (£433/2/6), 25 to US (£65/12/6)	a/a
1893	-	359bbl (£942/7/6)	359bbl to Gr. Brit. (£942/7/6)	a/a
1894	-	175bbl (£459/7/6)	175bbl to Gr. Brit. (£459/7/6)	a/a
1895	-	189bbl (£283/10)	162bbl to Gr. Brit. (£243), 10 to Br. West Indies (£15), 17 to Br. Guiana (£25/10)	a/a
1896	4 boats, 28 men	216bbl (£324)	216bbl to Gr. Brit. (£324)	a/a
1897	5 boats, 24 men	293bbl £469)	181bbl to Gr. Brit. (£271/10), 2 to Br. Guiana (£3)	a/a
1898	4 boats, 26 men	193bbl (£238)	189bbl to Gr. Brit.	a/a
1899	4 boats, 28 men	254bbl (£397/3/1)	252bbl to Gr. Brit. (£420), 2 to US (£3/6/8)	a/a; ave. price of oil £1/13/4 per bbl
1900	4 boats, 28 men	430bbl (£448/6/8)	553bbl to Gr. Brit. (£921/13/4) (<i>sic</i>)	-
1901	Failed to read	-	-	-
1902	5 boats, 39 men	405bbl (<i>ca</i> £600)	274bbl to Gr. Brit.	-
1903	5 boats, 41 men	288bbl (£350)	164 casks to Gr. Brit. (<i>f</i> 273/6/8)	£1/13/4 per cask
1904	5 boats, 41 men	12bbl (£20)	12 casks to Br. West Indies	£1/13/4 per cask
1905	6 boats, 42 men	42bbl (£70)	42bbl to Gr. Brit.	-
1906	5 boats, 33 men	250bbl (£156)	151bbl to Gr. Brit., 1 to Br. West Indies	-
1907	3 boats, 21 men	72bbl (£288)	72bbl to Gr. Brit.	-
1908	3 boats, 21 men	74bbl (£148)	74bbl to Gr. Brit.	£2/bbl
1909	2 boats, 12 men	14bbl (£28)	14bbl to Gr. Brit.	a/a
1910	2 boats, 12 men	28bbl (£58)	28bbl to Gr. Brit., 1 to Br. West Indies	a/a
1911	-	-	-	'No Whale Oil exported in 1911'.

Grenada

Non-mechanised shore whaling catches for Grenada were subsumed in the Grenadines column of table 1 in Mitchell and Reeves (1983) except for the 1921-24 period when, as mentioned earlier, they were erroneously listed in the Barbados column. Additional information from Romero and Hayford (2000) suggests that rather than a total of seven whales, as listed for 1921-24 by Mitchell and Reeves (based on published oil production data, and after applying a loss rate factor of 1.5), the Grenada secured catch was about 8-12 whales in 1920, one in 1921, no records in 1922, at least five

in 1923 and one in 1924, for a total of at least 15-19 whales landed. No information was found concerning catches after closure of the Norwegian whaling station at Grenada in 1926-27 (see above).

Trinidad

The shore whaling enterprise at Trinidad, previously poorly documented (Mitchell and Reeves, 1983), is now accounted for in some detail (Reeves *et al.*, 2001a).

St Lucia

Mitchell and Reeves (1983), citing Brown (1945), listed Pigeon Island near St Lucia as the site of a shore whaling station, apparently some time in the late 19th or early 20th century. It may be useful to search the St Lucia Blue Books for more details.

Turks and Caicos

A whaling station at Whale House Bay on Salt Cay in the Turks and Caicos group remains a mystery. The supposed timing of its demise, in the 1880s (Buissert and Clark, 1974), coincides with the decline of American pelagic whaling for humpback whales in the West Indies (Mitchell and Reeves, 1983) and the closing of some shore stations (e.g. in Trinidad; Reeves *et al.*, 2001a). Reeves checked the Turks and Caicos Blue Books for 1870, 1875, 1880, 1882, 1884, 1886 and 1888 in the Public Record Office. The sections 'Returns from Agriculture' and 'Returns from Manufactures, Mines, and Fisheries' consistently emphasised that the staple export was salt, supplemented by sponge, turtle shells, guano and 'cave earth'. In 1870, 25gal of whale oil (worth £2 12s.) was exported to St Thomas and in 1882 some spermaceti (worth £14 3s. 3d.) was trans-shipped to the United States. No reference of any kind was made, however, to local whaling in the Turks and Caicos.

CAPE VERDE ISLANDS: NON-MECHANISED SHORE WHALING

Clarke (1954) found 'no reference to any shore whaling from the Cape Verdes although sperm whales certainly frequent the islands, at least in winter'. In a study focussed on American pelagic whaling around the Cape Verde Islands, Reeves *et al.* (In press) found only meagre evidence of shore whaling. However, Reiner *et al.* (1996) and Hazevoet and Wenzel (2000) cited evidence of shore whaling at the Cape Verde Islands from as early as the late 18th century and into the early 20th century. Their main Portuguese-language sources (Cardoso, 1896; Carreira, 1983) merit closer examination to establish periods and scales of these operations and to confirm that the humpback (as opposed to the sperm whale or pilot whale [most likely *Globicephala macrorhynchus* in this area]) was their primary target.

MADEIRA: NON-MECHANISED SHORE WHALING

This whaling began in 1941 as an extension of the Azores open-boat fishery for sperm whales (Clarke, 1954) and continued until 1981 (IWC, 1988). Although sperm whales were the principal targets, large mysticetes were taken at least opportunistically (e.g. two right whales in 1967 —Maul and Sergeant, 1977).

AMERICAN NON-MECHANISED PELAGIC WHALING

The American ('Yankee') whale fishery, although largely centred on sperm and right whales, involved humpback whaling in a number of winter breeding areas including the West Indies and Cape Verde Islands (Clark, 1887; Townsend, 1935; Mitchell and Reeves, 1983).

West Indies

American pelagic whaling in the West Indies was identified by Mitchell and Reeves (1983) as a major component of the overall catch history of North Atlantic humpback whales. Those authors did not, however, estimate takes by American pelagic whalers in the West Indies prior to 1850 as their summary table of catches began only with that year. Available information on pre-1850 catches is summarised below and some new post-1850 data are also presented, allowing further analyses of post-1850 catches (IWC, 2002b).

Mitchell and Reeves (1983) repeatedly emphasised that their estimation procedures were intended to give negatively biased (i.e. 'conservative') results. A major source of negative bias that affected their estimates was that they sampled only two collections of whaling logbooks and journals in the northeastern USA — Providence Public Library and Old Dartmouth Historical Society. In a subsequent, similar study of right whaling in the North Atlantic, Reeves and Mitchell (1986a) found numerous relevant 19th century manuscripts in the collections of the Kendall Whaling Museum, Dukes County Historical Society and New Bedford Free Public Library. Clearly, the search by Mitchell and Reeves (1983) of logbooks and journals available in public collections at the time of their study was far from complete (Sherman *et al.*, 1986).

New England whalers began visiting the West Indies from at least as early as 1772 but it is uncertain whether they took many humpback whales in the first few decades (Mitchell and Reeves, 1983). The schooner *Lark* of Nantucket hunted sperm, humpback and pilot whales there in 1785 (Reeves and Mitchell, 1986a). Mitchell and Reeves (1983) concluded that humpback whaling in the West Indies did not become a 'regular feature' of the American fishery until after 1836. The South Seas whale fishery occupied most of the world's large vessels during the late 18th and early 19th centuries and some of these whaleships sailed from British or French ports (Stackpole, 1972; Du Pasquier, 1982). The itineraries of most American vessels took them eastward to the Western Islands (Azores) thence southward via the Canaries and Cape Verdes into equatorial waters or the South Atlantic. If they visited the West Indies, it was most likely during the return voyage, perhaps stopping at Barbados to trans-ship oil and baleen, then pursuing sperm whales on the Bahamas, Southern, Charleston or Hatteras Grounds before arriving back in New England. A few smaller vessels, particularly those from ports such as Provincetown, Westport and Boston, stayed in the North Atlantic and sometimes visited the West Indies. For example, in 1822 the brig *Laurel*, instead of heading directly back to New England from the Azores in the autumn, spent several months in the West Indies and arrived home in March 1823 (Atwood in Clark, 1887; returning only sperm oil according to Starbuck, 1878). In 1836, four Provincetown vessels took some humpback whales in the West Indies (Atwood in Clark, 1887) although Starbuck (1878) gave the destinations of Provincetown vessels in 1835-37 as 'Cape de Verdes' or 'Atlantic' and indicated that they returned only sperm oil.

The sample of unpublished logbooks and journals studied by Mitchell and Reeves (1983) revealed a number of additional voyages in which humpback whales were pursued between 1822-49 (also see Reeves *et al.*, 2001b) but only a single catch (and one struck/lost) was documented (*Industry of Westport*, 1828). In subsequent studies, Reeves found evidence of 15 additional West Indies voyages between 1833-43 but only two more catches and one more struck/lost humpback (Table 3). If it is assumed that all of the *whale* oil

returned by these voyages (693bbl) came from humpback whales, this represents an estimated total catch of only 28 whales (i.e. less than 3/year) using 25bbl/whale for conversion. It must be emphasised, however, that searches of logbooks, newspapers and other sources were not comprehensive.

The figures attributed by Mitchell and Reeves (1983) to 'Yankee Pelagic West Indies' for 1850-65 in their table 1 came only from their 'read' sample (secured, killed/lost, orphaned calves, struck/lost carrying gear, and half of the struck/lost without gear or unspecified) and 'sighted' sample (mid-point of oil-based and vessel-season estimates; see their table 11 for the sample and table 12 for the method). No extrapolation was involved. A number of factors suggest that the catches were much higher than indicated during that period. The most obvious one is that many humpbacking voyages must have been missed simply because the logbooks were not held by either the Providence Public Library or the Old Dartmouth Historical Society. Provincetown whaling effort in the North Atlantic was roughly constant throughout the period and substantial quantities of humpback oil were landed at New Bedford (Mitchell and Reeves, 1983). Although the value of whale oil was highly variable (see Bockstoce, 1986, for the reasons), it spiked markedly from 1862-67 (Mitchell and Reeves, 1983).

For the period 1866-87, which Mitchell and Reeves (1983) considered the peak of American pelagic whaling for humpback whales in the West Indies, they added an 'extrapolated' component to account for voyages not included in their 'read' or 'sighted' samples. This component was narrowly constrained. For inclusion, a voyage had to have: (a) originated in Provincetown; (b) sailed between the years 1866-87; (c) departed home port between the months October-March, inclusive; (d) returned to home port before the following winter; (e) shown some return of whale oil; and (f) shown no return of any 'bone' (baleen). The relatively large catches for the years 1866-87 attributed to 'Yankee Pelagic West Indies' in their table 1 came directly from their table 12, where the procedures and underlying assumptions were explained.

Table 3 of the present paper lists numerous voyages that are now known to have taken humpback whales but that were not accounted for in any of the estimates by Mitchell and Reeves (1983). In addition, based on data in Starbuck (1878) and Hegarty (1959) regarding sailing and arrival dates and amounts of whale oil returned, several hundred American voyages between 1866-87 could have taken humpback whales in the West Indies (or Cape Verdes) but were not included in the 'read,' 'sighted' or 'extrapolation' samples of Mitchell and Reeves (1983). Among the possible reasons are that: (a) no logbook or journal was available in either of the two collections used by Mitchell and Reeves (i.e. it could not have been 'read'); (b) no record of the vessel's presence on the West Indies whaling grounds was found in the read logbooks and journals (i.e. it was not 'sighted'); or (c) the voyage's characteristics did not meet the narrow criteria established by Mitchell and Reeves for inclusion in their 'extrapolation' sample (see the foregoing paragraph). In a more detailed analysis, using different methods and additional logbook data, Smith and Reeves (2002) concluded that the catch estimates by Mitchell and Reeves (1983) were negatively biased but by less than expected, and that it was appropriate to stratify voyages on the assumption that those leaving from Provincetown were far more likely to humpback in the West Indies than those leaving from other American ports.

Cape Verde Islands

Some humpbacking by American whalers took place at the Cape Verde Islands as early as 1816 although a substantial increase in effort seems to have occurred in the 1830s (Reeves *et al.*, 2002). The peak appears to have been in the 1850s to mid-1860s, somewhat earlier than the peak of effort and catch in the West Indies. Although their study emphasised Yankee whaling in the West Indies, Mitchell and Reeves (1983) recorded data for five vessel-seasons of humpbacking in the Cape Verdes (1853, 1870, 1877, 1882 and 1883), accounting for a total of at least 35 whales secured, ten killed but lost, 29 struck but lost and two orphaned calves. Reeves and Mitchell (1986a) identified several additional voyages that either definitely or probably included periods of humpback whaling in the Cape Verdes; these were in the years 1857-59 and 1864-65 and usually also involved whaling for right whales in Cintra Bay, West Africa.

Reeves *et al.* (2002) examined the American humpback fishery in the Cape Verdes and provided estimates of kills and strikes based on data from logbooks and journals, the Dennis Wood Abstracts (Wood, no date) and various published sources.

Other areas

Nantucket whalers made voyages to Greenland (Davis Strait) and Newfoundland (Grand Bank or Gulf of St Lawrence) as early as the 1730s (Little, 1988) although according to Macy (1835) they did not begin whaling in Davis Strait until 1746, the Gulf of St Lawrence in 1761 and grounds east of the Grand Bank in 1765. Nantucket sent an average of 102 (range 60-125) ships on whaling voyages each year from 1762-72, returning an average total of 12,745bbl of oil (range 7,825-19,140; presumably whale oil and sperm oil combined) (Macy, 1835). A large fleet of American vessels whaled in the Gulf of St Lawrence and Strait of Belle Isle in the 1760s (Starbuck, 1878; see summary in Mitchell and Reeves, 1983).

With the decline of right whales throughout the North Atlantic by the mid-18th century, humpback whales became tolerable substitutes and their oil probably constituted an increasing proportion of the returns labelled 'whale oil' (as opposed to sperm oil). For example, the sloop *Seaflower* of Nantucket sailed to Newfoundland in June 1752 with the explicit purpose 'to kill Some Humps'. According to its logbook, the *Seaflower* and six other Nantucket sloops returned with more than 100bbl of 'Humpback oyl' aboard each of them (Reeves and Mitchell, 1986a). A simple interpretation of this information would be that close to 30 humpback whales were taken by the Nantucket fleet in Newfoundland that season (assuming 25bbl/whale). American whaling for humpback whales in eastern Canadian (and Newfoundland) waters seems to have been a substantial enterprise for roughly a century, beginning in the mid-1700s. References summarised by Mitchell and Reeves (1983) indicate that considerable numbers of this species were still being taken by American whalers around Newfoundland and in the Gulf of St Lawrence during the middle of the 19th century. In addition to the whales taken by vessels declaring these areas as their primary destination, other whales probably were taken or at least struck by whalers while *en route* to or on other grounds, particularly in the second half of the 19th century when shoulder guns and bomb lances were available. For example, the bark *Charles W. Morgan* of New Bedford (1878-81, MS) took a 28bbl humpback from a

[text continues on p. 231]

Table 3

Previously unpublished data on West Indies humpback whaling (i.e. not included in Mitchell and Reeves, 1983). * = logbook/journal was read some time after 1983 (see references). ** = voyage was included in 'sighted' or 'extrapolation' sample of Mitchell and Reeves (1983) but that logbook/journal has been read since 1983. *** = voyage was included in 'sighted' or 'extrapolation' sample of Mitchell and Reeves (1983) but that new data are now available as indicated. Sp = sperm oil (bbl); wh = whale oil (bbl); bone = whalebone or baleen (lb).

Vessel/year of departure	Rig/port	Season in W. Indies	Whales secured ¹	Whales killed but lost	Whales struck but lost	Published returns ²	Comments
<i>Harmony</i> /1833	Schooner/Nantucket	1833-34	Uncertain			Unclear	See Reeves <i>et al.</i> , 2001a
<i>Harmony</i> /1835	Schooner/Nantucket	1836	Uncertain			260sp, 150wh	Called at Port-of-Spain, Trinidad, 'in distress', 23 Feb. (Reeves <i>et al.</i> , 2001a)
* <i>Annawan</i> /1836	Brig/Rochester	1837	1 (calf)		1	178sp, 20wh	Whaled off Venezuela and Trinidad (<i>Annawan</i> , 1836-37)
<i>Popmunnett</i> /1837	Bark/Falmouth	1837	1(+?)			300sp	30bbl humpback oil on board as of 7 Feb.; whaled off Venezuela (<i>Annawan</i> , 1836-37) and Trinidad (Reeves <i>et al.</i> , 2001a)
<i>Primrose</i> /1836	Schooner/Nantucket	1837	Uncertain			100sp, 50wh	Called at Port-of-Spain, Trinidad, 'on a whaling voyage', 28 Mar. (Reeves <i>et al.</i> , 2001a)
<i>Elizabeth</i> /1836	Brig/Westport	1837	Uncertain			212sp, 13wh	Seen at Bequia 1 Feb. (<i>Annawan</i> , 1836-37)
<i>Little Catherine</i> /1836?	Bark/London	1837	Uncertain			?	Called at Port-of-Spain, Trinidad, 'with Apparatus for catching Whales', 31 Jan. (Reeves <i>et al.</i> , 2001a)
<i>Popmunnett</i> /1838	Bark/Falmouth	1838	Uncertain			200sp	Called at Port-of-Spain, Trinidad, 'from a whaling voyage', 14 Mar.; sailed 16 Mar. 'on a whaling voyage' (Reeves <i>et al.</i> , 2001a)
<i>Primrose</i> /1838	Schooner/Nantucket	1838	Uncertain			Clean	Called at Port-of-Spain, Trinidad, 'with implements for whaling', 23 Mar.; sailed 24 Mar. 'on a whaling voyage' (Reeves <i>et al.</i> , 2001a)
<i>Harmony</i> /1837	Schooner/Nantucket	1838	Uncertain			130sp	Called at Port-of-Spain, Trinidad, 'from a whaling voyage' with 'oil and implements for whaling', 23 Feb. (Reeves <i>et al.</i> , 2001a)
<i>Imogene</i> /1838	Brig/Provincetown	1838	Uncertain			400sp, 200wh	Called at Port-of-Spain, Trinidad 'on a Whaling Voyage', 25 Mar. (Reeves <i>et al.</i> , 2001a)
<i>Imogene</i> /1839	Brig/Provincetown	1839	Uncertain			350sp, 250wh	Called at Port-of-Spain, Trinidad 'with whaling apparatus', 4 Feb. (Reeves <i>et al.</i> , 2001a)
<i>Sarah</i> /1840?	Bark (Brig?)/Rochester?	1842	Uncertain			624sp?	Called at Port-of-Spain, Trinidad 'from a whaling voyage', 10 Jan. (Reeves <i>et al.</i> , 2001a)
<i>Fairy</i> /1842	Bark/Provincetown	1843	Uncertain			300sp, 30wh	Called at Port-of-Spain, Trinidad 'from a whaling voyage', 21 Jan.; sailed 24 Jan 'on a whaling voyage' (Reeves <i>et al.</i> , 2001a)
<i>Edward</i> /1842	Brig/Mattapoisett	1843	Uncertain			420sp	Called at Port-of-Spain, Trinidad, 'from a whaling voyage', 25 Feb. (Reeves <i>et al.</i> , 2001a)
<i>Corvo</i> /1852	Bark/Orleans	1853	Uncertain			360sp	Seen off Venezuela 4 Feb. (<i>Solon</i> , 1852-53)
* <i>Winged Racer</i> /1867	Schooner/Provincetown	1867	5			Nothing	Humpbacking in Mona Passage (<i>Winged Racer</i> , 1867)
<i>Watchman</i> /1867	Schooner/Provincetown	1867	Uncertain			40sp	Seen in Mona Passage 15 Mar. (<i>Winged Racer</i> , 1867)
** <i>Winged Racer</i> /Jan. 1868	Schooner/Provincetown	1868	1 ½ [3]			50sp, 40wh	Humpbacking in Mona Passage (<i>Winged Racer</i> , 1868)
*** <i>Ellen Rizpah</i> /1868	Schooner/Provincetown	1868	At least ½ [4]			77sp, 58wh	Humpbacking in Mona Passage in co. with <i>Winged Racer</i> from at least 9 Feb.-1 Apr. (<i>Winged Racer</i> , 1868)
** <i>Winged Racer</i> /Dec. 1868	Schooner/Provincetown	1869	4 [7]	1	3	100wh	Humpbacking in Grenadines, landed some oil at St Vincent 16 May (<i>Winged Racer</i> , 1868-69)
** <i>Rising Sun</i> /1875	Schooner/Provincetown	1875	2 [4]			159sp, 60wh	Humpbacking at Mariegalante (<i>Rising Sun</i> , 1875-83)
<i>Gracie M. Parker</i> /1874 or 1875	Schooner/Provincetown	1875	1-2(+?)			No report	Reported at Mariegalante 30 Apr. with 150bbl whale oil; seen at Mariegalante 11 May fast to cow/calf (<i>Rising Sun</i> , 1875-83)
*** <i>Lottie E. Cook</i> /1875	Schooner/Provincetown	1875	1(+?) [14]			20sp, 190wh	Reported at Mariegalante 30 Apr. with 55bbl whale oil after 6 weeks out; seen at Mariegalante 11 May processing a whale (<i>Rising Sun</i> , 1875-83)
*** <i>Ellen Rizpah</i> /1875	Schooner/Provincetown	1875	Some [16]			220wh	Seen at Mariegalante 30 Apr. with 150bbl HB oil after 2 months (<i>Rising Sun</i> , 1875-83)
** <i>Rising Sun</i> /1876	Schooner/Provincetown	1876	3 (cows), 2 others [15]	1 cow, 1 other	1	100sp, 200wh	Humpbacking at Mariegalante (<i>Rising Sun</i> , 1875-83)
*** <i>Gracie M. Parker</i> /1876	Schooner/Provincetown	1876	1/2(+?) [15]			165sp, 200wh	Seen humpbacking at Mariegalante 13 Mar.-at least 3 Apr.; took a whale 23 Mar. in co. with <i>Arizona</i> (<i>Rising Sun</i> , 1875-83)
*** <i>M.E. Simmons</i> /1876	Schooner/Provincetown	1876	Probably some [15]			150sp, 200wh	Seen humpbacking at Mariegalante 14 Mar.-at least 3 Apr. (<i>Rising Sun</i> , 1875-83)
*** <i>Arizona</i> /1876	Schooner/Provincetown	1876	1/2(+?) [1]			80sp, 20wh	Seen humpbacking at Mariegalante 23 Mar.-at least 3 Apr.; took a whale 23 Mar. in co. with <i>G.M.Parker</i> (<i>Rising Sun</i> , 1875-83)
*** <i>Edward Lee</i> /1876	Schooner/Provincetown	1876	Some [13]			180wh	Seen humpbacking at Mariegalante 3 Apr. (<i>Rising Sun</i> , 1875-83)

cont...

Table 3 continued.

Vessel/year of departure	Rig/port	Season in W. Indies	Whales secured ¹	Whales killed but lost	Whales struck but lost	Published returns ²	Comments
** <i>Rising Sun</i> /1877	Schooner/Provincetown	1877	2 cows (40 & 70bbl), 1 other (20bbl) [10]			100sp, 130wh	Humpbacking at Mariegalante (<i>Rising Sun</i> , 1875-83)
*** <i>M.E. Simmons</i> /1876	Schooner/Provincetown	1877	1+ [22]			160sp, 300wh	Took 23bbl whale at Mariegalante 26 Mar. 1877; seen chasing cow/calf 14 Apr.; took a whale 23 Apr. (<i>Rising Sun</i> , 1875-83)
*** <i>Gracie M. Parker</i> /1877	Schooner/Provincetown	1877	3 cow/calf pairs, 1 other (+?) [19]			175sp, 250wh	Took cow/calf pairs at Mariegalante 31 Mar., 3 Apr., 16 Apr. (60bbl for one of these pairs), 1 other 21 Apr. (<i>Rising Sun</i> , 1875-83)
*** <i>Ellen Rizpah</i> /1877	Schooner/Provincetown	1877	Probably some [15]			125sp, 200wh	Seen at Mariegalante 19 Apr. with 200bbl whale oil (<i>Rising Sun</i> , 1875-83)
*** <i>Lottie E. Cook</i> /1877	Schooner/Provincetown	1877	Probably some [13]			50sp, 180wh	Seen at Mariegalante 2 May with 180bbl whale oil after 2½ months out (<i>Rising Sun</i> , 1875-83)
* <i>Rising Sun</i> /1878	Schooner/Provincetown	1878	1 calf, 1 other			No report	Humpbacking in Grenadines; sold 151gal HB oil at St Vincent (<i>Rising Sun</i> , 1875-83)
<i>Agate</i> /1877	Schooner/Provincetown	1878	Uncertain			120sp, 100wh	Seen at Tobago 27 Feb. (<i>Rising Sun</i> , 1875-83)
<i>Antarctic</i> /1877	Schooner/Provincetown	1878	Uncertain			340sp, 100wh	Seen at Tobago 28 Feb. (<i>Rising Sun</i> , 1875-83)
<i>Ellen Rizpah</i> /1878	Schooner/Provincetown	1878	Uncertain			80sp, 170wh, 1900bone	Seen in Grenadines 7 Mar. (<i>Rising Sun</i> , 1875-83)
*** <i>Gracie M. Parker</i> /1878	Schooner/Provincetown	1878	Uncertain [16]			90sp, 210wh	Seen in Grenadines 7 Mar. (<i>Rising Sun</i> , 1875-83)
** <i>Rising Sun</i> /Feb 1879	Schooner/Provincetown	1879	[6]			330sp, 80wh	The whale oil for this voyage <i>did not</i> come from West Indies humpbacks (<i>Rising Sun</i> , 1875-83)
<i>Edward Lee</i> /1879	Schooner/Provincetown	1879	Uncertain			70sp, 190wh	Seen at St Bart's 15 Apr. 1879 with 70 bbl 'Black oil' after 2½ mo. out (<i>Rising Sun</i> , 1865-83)
** <i>Rising Sun</i> /Nov. 1879	Schooner/Provincetown	1880	1 calf, 2 others [6]	1 cow, 3 others	2 cows, 1 other	65sp, 80wh	Humpbacking at Mariegalante (<i>Rising Sun</i> , 1875-83)
*** <i>Agate</i> /1880	Schooner/Provincetown	1880	at least 1 cow/calf, 2 others [19]			70sp, 260wh	Seen humpbacking at Mariegalante 6 Mar.-at least 15 Apr. (see <i>Rising Sun</i> , 1875-83); took cow/calf 17 Mar.; another whale 8 Apr. (saved bone); seen processing a whale 1 May (see <i>Carrie W. Clark</i> , 1879-81)
*** <i>Mary G. Curran</i> /1880	Schooner/Provincetown	1880	Probably some [9]			80sp, 115wh	Seen at Mariegalante, apparently humpbacking, 1 May (see <i>Carrie W. Clark</i> , 1879-81)
** <i>Rising Sun</i> /1882	Schooner/Provincetown	1882	Some [12]			200sp, 160wh	Humpbacking at Mariegalante (<i>Rising Sun</i> , 1875-83)
** <i>Rising Sun</i> /1883	Schooner/Provincetown	1883	5 cow/calf pairs (made 40 and 55bbl from 2 of these), 3 others (made 38bbl from 1 of these) [16]	1	1 calf	30sp, 215wh	Humpbacking at Mariegalante; saved baleen from humpbacks (<i>Rising Sun</i> , 1875-83)
* <i>Leonidas</i> /1864	Bark/New Bedford	1865	1 cow (42bbl; calf also struck)	1 calf killed but not processed	3	21sp, 42wh, sent home 155sp	Humpbacking at Bequia; delivered 28bbl oil to agent at St Vincent; sold 13gal HB oil at St Vincent, 105gal at St Eustatius (<i>Leonidas</i> , 1864-65)
* <i>Rainbow</i> /1866	Schooner/Dartmouth	1867	3 cows (at least struck at least 1 of the calves), 1 other	1	2	35sp, 3wh	Humpbacking off Trinidad (<i>Rainbow</i> , 1866-67); see Mitchell and Reeves (1983: table 9) for under-representation of catch for this voyage
<i>George J. Jones</i> /1866	Schooner/Fairhaven	1867				100sp, sent home 179sp	Seen at Trinidad 8 Feb.-at least 20 Mar.; humpbacking in co. with <i>Rainbow</i> (<i>Rainbow</i> , 1866-67)
<i>George J. Jones</i> /1870 (see <i>Thraver</i> 1870-71)	Schooner/Fairhaven	1871			at least 1	109sp, 135wh, sent home 30sp	Humpbacking off Venezuela; struck a whale 1 Mar. at Purata Island (<i>Thraver</i> , 1870-71)
*** <i>Ellen Rizpah</i> /1883	Schooner/Provincetown	1883	[15]			75sp, 200wh	Seen at St Lucia 2 Mar. (<i>Union</i> , 1882-83)
<i>Fanny Burns</i> /1882	Schooner/New Bedford	1883				No returns indicated	Seen at St Lucia 19 Mar. (<i>Union</i> , 1882-83)

cont...

Table 3 continued.

Vessel/year of departure	Rig/port	Season in W. Indies	Whales secured ¹	Whales killed but lost	Whales struck but lost	Published returns ²	Comments
* <i>Washington</i> /1858	Schooner/Edgartown	1859	1½ (1 gave 22bb1)			170sp, 37wh, sent home 46sp	Humpbacking at Dominica in co. with <i>Orray Taft</i> (<i>Washington</i> , 1858-59)
<i>Orray Taft</i> /1858	Bark/New Bedford	1859	At least ½			600wh, 9000bone, sent home 449sp	Humpbacking in co. with <i>Washington</i> at Dominica 21 Feb. (see <i>Washington</i> , 1858-59)
* <i>Eschol</i> /1871	Brig/Beverly	1872	1 cow	1 cow/calf, 1 calf killed but not processed		150sp, sent home 149sp	Humpbacking at Mariegalante at least 9 Mar.-7 May (<i>Eschol</i> , 1871-72)
*** <i>Ellen Ripah</i> /1872	Schooner/Provincetown	1872	At least 2 (1 gave 20bb1) [16]			112sp, 214wh	Humpbacking at Mariegalante; took a whale 2 Apr., another 12 Apr. (<i>Eschol</i> , 1871-72)
*** <i>Arizona</i> /1872	Schooner/Provincetown	1872	At least 2 (1 gave 20bb1) [16]			221wh	Humpbacking at Mariegalante; took a whale 6 Apr., another 12 Apr. (<i>Eschol</i> , 1871-72)
*** <i>B.F. Sparks</i> /1872	Schooner/Provincetown	1872	At least 1 cow/calf [19]			75sp, 254wh	Humpbacking at Mariegalante; took a cow/calf 10 Apr. (<i>Eschol</i> , 1871-72)
*** <i>Gracie M. Parker</i> /1872	Schooner/Provincetown	1872	At least 1 [24]			105sp, 323wh	Humpbacking at Mariegalante; took a whale 13 Apr. (<i>Eschol</i> , 1871-72)

¹Numbers in square brackets are catches (including loss rate factor × 1.85) for these voyages estimated by Mitchell and Reeves (1983). ²From Starbuck (1878) or Hegarty (1959).

group of three encountered west of the Two Forties Ground (40°N, 58°20'W) in early October 1878, during the outbound portion of a three-year voyage to the South Atlantic; the Westport bark *Mattapoisett* (1871-72, MS) took a cow-calf pair on the Western Ground (34°20'N, 43°40'W) in early June 1872, during the home-bound leg of a 14 month voyage to the South Atlantic; and the New Bedford brig *A.J. Ross* (1878) chased a group of humpback whales off Hamilton Inlet, Labrador, on 21 June 1878, while heading for Hudson Bay to hunt bowhead whales (*Balaena mysticetus*). It is impossible to estimate the magnitude of the opportunistic kills of humpback whales in the North Atlantic outside the breeding grounds, although such kills appear to have been exceptional rather than common.

OTHER AREAS AND FISHERIES

Venezuela

No evidence was found of 19th century shore whaling in Venezuela. However, considering that American and British whalers hunted humpback whales in coastal and inshore waters of Venezuela during the 1830s-1870s (Reeves *et al.*, 2001a; b), it would not be surprising to learn that they introduced equipment and techniques for whaling at sites on shore. Romero *et al.* (1997) cited records of this species being hunted with harpoons in Venezuelan waters in 1960, 1990 and 1993, but Romero *et al.* (2001) noted only that in early 1960 a stranded humpback had 'three embedded harpoons of Japanese origin' and made no mention of the 1990 and 1993 events. A humpback was taken incidentally in a fishing net at Ensenada de La Guardia, Isla Margarita, in February 1990; it was one of several seen in the bay that day (M. González, Miami, FL, 12 January 1999, *in litt.*, accompanied by photographs). In addition, a 630cm male stranded at La Salina (10°34'N, 67°05'W) in May 1990 (Boher and García, 1990). This appears to be the 1990 animal cited by Romero *et al.* (1997) as having been harpooned.

Early European whaling off Newfoundland and Labrador

Considering the ratio of humpback whales to other mysticetes on the Grand Bank and in coastal waters of Newfoundland and Labrador in recent years (e.g. Hay, 1982; Whitehead and Glass, 1985; Kingsley and Reeves, 1998), it is difficult to imagine that the large fleets from Spain, Portugal, France and Great Britain who were cod fishing and whaling for bowheads and right whales during the 16th century (Lubbock, 1937) did not catch humpback whales at least occasionally. Humpback whales were clearly less desirable, however⁵, and might have been largely ignored.

Some French whalers operated in the Strait of Belle Isle and along the north shore of the Gulf of St Lawrence during the first half of the 18th century. For example, one vessel reported taking 11 whales and striking 16 more in 1735 (Reeves, 1985; Reeves and Mitchell, 1986a). Although bowhead and right whales (*ballennes de grand Baye*) were clearly preferred, these whalers seem to have also pursued other mysticetes routinely. For example, nine of the 11

⁵ The Muscovy Company's instructions to Thomas Edge in 1611 on how to distinguish 'the better sorts' of whales from 'the worser' referred to the 'Sedeva Negro', described as black in colour, 'with a bumpe on his back', was said to yield 'neither oyle, finnes [i.e. baleen], nor teeth, and yet he is of great bignesse'. This has been interpreted as referring to the humpback (see Lubbock, 1937; Mead and Mitchell, 1984).

caught whales and all of the struck and lost ones in the aforementioned 1735 cruise were referred to as *gibarts*, which may have included humpback whales⁶.

CONCLUSIONS

The proposed definitions of fisheries and sub-fisheries in Table 1 appear to capture the scope and complexity of the humpback fishing operations in the North Atlantic. In geographic range, these operations took place from Iceland, Svalbard and northern Norway south to the Cape Verde Islands in the east, and from Greenland, Newfoundland and the Gulf of St Lawrence south to the West Indies and Venezuela in the west. While the time periods are well known for most of the fisheries and sub-fisheries, take levels (whether defined as landings alone, or as landings plus hunting loss) are only approximately known for many of them. More precise determinations of take levels will probably never be possible for some areas and times, but in most cases information on catch or production (e.g. oil) is available for at least some years.

The largest numbers of humpback whales, estimated as totalling more than 2,000 over the entire period of operation, were taken in two fisheries: the Icelandic sub-fishery of the Norwegian Mechanised Shore fishery and the West Indies sub-fishery of the American Non-mechanised Pelagic fishery. Fourteen other fisheries or sub-fisheries were each estimated to have taken hundreds but probably less than about 2,000 humpback whales. Of the other fisheries and sub-fisheries, six are thought to have taken only tens of whales and three to have taken negligible numbers (<10). Available information was inadequate to produce meaningful estimates for five of the fisheries or sub-fisheries (see IWC, 2002b).

Further historical study is warranted for several of the fisheries or sub-fisheries that are either known or suspected to have taken substantial numbers of humpback whales. These include, in particular, two of the sub-fisheries of the American Non-Mechanised Pelagic fishery (West Indies and Cape Verde Islands; see Smith and Reeves, 2002) and the Bermuda Non-mechanised Shore, Cape Verde Islands Non-mechanised Shore and American Mechanised Coastal fisheries (see Webb, 2001; Reeves *et al.*, 2002). Also, it would be useful if Nordic scholars were to address more fully the problem of pro-rating the unspecified whale catches (on an annual basis) during the early years of Norwegian Mechanised Shore whaling in Iceland and the Faroes. Because of the likely large magnitude of humpback removals in some of these fisheries, such work should be given high priority.

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⁶ Hershkovitz (1966) translated *gibbar* as the fin whale (*Balaenoptera physalus*) and *jubarte* as the humpback. True (1904) cited a 17th century French narrative describing the *Gibar* of the Gulf of St Lawrence as 'a kind of whale, so called on account of a protuberance that it seems to have, having the back much raised, where it carries a fin'. It is uncertain which species were included by the French whalers under the name *gibart* but the humpback could have been one of them.

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Humpback whale (*Megaptera novaeangliae*) occurrence near the Cape Verde Islands, based on American 19th century whaling records

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ABSTRACT

American 19th century whalers often passed through the Cape Verde Islands (CVI) during the boreal winter and some of them spent a few weeks or months hunting humpback whales (*Megaptera novaeangliae*) in the bays and near-shore waters of the archipelago. Logbooks were examined from 26 voyages that involved some humpback whaling at the CVI, and information was obtained from various sources on approximately 77 additional voyages that definitely or probably humpbacked there. Twenty of the logbooks contained 396 records of an estimated 1,105 humpback whale encounters (catches, strikes and sightings). The largest estimated numbers of encounters and most of the whaling activity were around the islands of Sal, São Vicente and São Nicolau (272, 269 and 229 encounters, respectively). The peak month for humpback whale occurrence in the region appears to have been March (160 records of an estimated 465 whale encounters), with many records from February (110 records of 282 encounters) and April (86 records of 258 encounters). Catch data from the logbooks were combined with commercial data on landings of oil and reported vessel positions to estimate numbers of humpback whales taken in the CVI by the American fleet. Results suggest that American whaling for humpback whales was most intensive in the Cape Verdes during the 1850s and 1860s when at least a few hundred and perhaps more than 500 whales were killed in at least 45 and perhaps more than 80 vessel-seasons. In many respects, the Cape Verdes fishery was similar to that in the West Indies, with cows and calves frequently taken and a similar seasonal peak in whale occurrence. A crude analysis of encounter rates suggests that humpback whale density in the CVI was comparable to that in the major West Indies grounds, a situation that is clearly not the case today.

KEYWORDS: WHALING – HISTORICAL; HUMPBACK WHALE; CAPE VERDE ISLANDS; WEST INDIES; NORTH ATLANTIC; DISTRIBUTION; CATCH HISTORY

INTRODUCTION

Humpback whales (*Megaptera novaeangliae*) occur during the boreal winter and spring around the Cape Verde Islands (CVI), a volcanic archipelago located directly west of Senegal in western Africa (Fig. 1). This seasonal concentration of whales was well known to American whalers during the 19th century (Clark, 1887b; Kellogg, 1929) and some of them spent a few weeks or months cruising for humpback whales on these grounds. Another seasonal concentration, also exploited by the 19th century whalers, occurs farther south along the African coast, centred in the Gulf of Guinea from the Equator south to about 7°S (Clark, 1887b; Townsend, 1935; Aguilar, 1985; Walsh *et al.*, 2000). This latter concentration forms primarily during the austral winter (June–October) and probably consists of Southern Hemisphere animals that migrate to the Antarctic in the summer (Hinton, 1926; Kellogg, 1929; Mackintosh, 1965; Mackintosh and Brown, 1974).

The importance of the Cape Verde archipelago as a wintering ground for humpback whales has sometimes been ignored or underestimated despite references in the literature to substantial catches there (Clark, 1887b; Townsend, 1935; Mitchell and Reeves, 1983; Reeves and Mitchell, 1990; Reiner *et al.*, 1996). Mitchell and Reeves (1983) read logbooks or journals of six American humpbacking voyages to the CVI between 1853–84, recording 45 animals secured and 29 struck but lost. Six additional humpbacking voyages to the CVI were mentioned in passing by Reeves and Mitchell (1986).

The CVI, like the West Indies, were attractive primarily because of their proximity to good sperm whale (*Physeter macrocephalus*) and blackfish (pilot whale, *Globicephala*

spp.) grounds, their strategic location for sailing south from the Azores and Canaries towards the equatorial and southern whaling and sealing grounds, and their mild winter climate. As explained by Hall (1982),

‘The first leg of a whaling voyage from New Bedford frequently consisted of a transatlantic passage to either the Azores or Cape Verde Islands, which with the aid of the prevailing winds could be accomplished within four to six weeks. The islands offered an opportunity to obtain fresh food and to ship additional crew if necessary’

(also see, e.g. Ferguson and Stair, 1936; Fuller, 1980; Haley, 1950). São Nicolau was said to be the ‘most pleasant’ island while Brava was the most lush (Hall, 1982). The island of Sal was a major source of salt for sealing vessels headed towards the Southern Ocean, the salt being used to preserve sealskins (Busch, 1985; Dodge, 1986). Not all whalers that stopped at the CVI, even in the winter and early spring, made an effort to hunt humpback whales. For example, the New Bedford brig *A.J. Ross* visited São Vicente in 1878 following an unsuccessful three-week cruise to Cintra Bay, western Africa, for right whales (*Eubalaena glacialis*). The crew was given shore liberty for a drinking binge. Then, after a few more days at Brava where several crew members were enlisted, the *Ross* set sail for Bermuda (Tilton, 1969).

During the 1880s–1890s, the ‘San Antonio Ground’ in the CVI (also sometimes called ‘the Twenty-Twenties’; Townsend, 1935) was a popular area for hunting sperm and pilot whales between December and March (*George and Mary*, 1888–91, MS; 1892–94, MS). Clark (1887b) described the preferred sperm whale grounds in the southeastern North Atlantic as being along the southern coast of Portugal and Spain from Cape St Vincent to the Strait of Gibraltar, near

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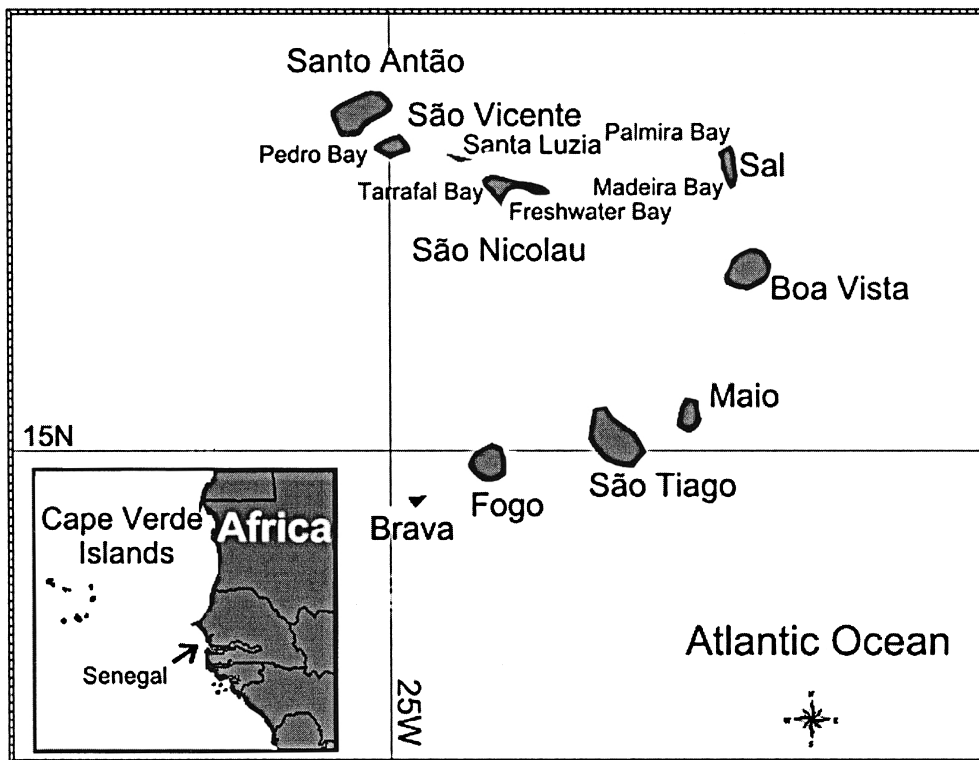


Fig. 1. Map of Cape Verde Islands study area.

the south coast of Tenerife, north and west of the CVI (especially in the winter) and in the areas 10–14°N, 35–40°W (March–May) and 5–7°N, 18–20°W (winter). This latter is what Townsend (1935) called the ‘Cornell Ground’, centred at 4°N, 22°W. Some American whalers, especially the schooner fleet from Provincetown, would cruise near shore for humpback whales at the CVI in the winter, then head north to the sperm whale grounds in the spring or summer (Clark, 1887b). Those North Atlantic whaling vessels that did not stay in the CVI for the humpbacking season often headed west to visit the ‘Twelve-Forty Ground’ (12°N, 40°W) between the CVI and the West Indies from February to May (Townsend, 1935). According to Berzin (1972), waters along 25°W longitude, centred between the CVI and the Equator, constituted an important historical sperm whaling region, with the best whaling there from October to March. The CVI archipelago was also a convenient base for going to and returning from the Cintra Bay Ground on the coast of Africa where right whales were hunted in the boreal winter by some American vessels (Reeves and Mitchell, 1986). However, the small concentration of ‘humpback’ catch positions plotted by Townsend (1935) along the Rio de Oro coast of Africa is misleading. He and his associates seem to have mistaken right whales for humpbacks in their logbook references from this area (Reeves and Mitchell, 1990).

Here, logbooks and journals (both referred to as ‘logbooks’ hereafter) from American whaling vessels are used to investigate the occurrence and distribution of humpback whales in the CVI during the 19th century, in an effort to assess the importance of this region as an historic breeding ground. Results are compared to those from a similar study of 19th century humpback whaling in the West Indies (Reeves *et al.*, 2001). Another main objective of the present study was to document in greater detail the nature, timing and scale of American humpback whaling at the CVI.

MATERIAL AND METHODS

Identifying the logbook sample

In addition to compiling data on CVI whaling from the literature, a non-random sample of logbooks from key collections in New England museums and libraries was examined (Table 1). The goal was to check as many ‘promising’ logbooks as possible within the project’s time and budget constraints. ‘Promising’ meant that information was available to confirm or suspect that humpback whales were hunted in the CVI at some point in the voyage. Such information came from: (a) earlier similar studies that focussed on humpback whaling in the West Indies (Mitchell and Reeves, 1983; Reeves *et al.*, 2001) or right whaling in the North Atlantic (Reeves and Mitchell, 1986); (b) the Dennis Wood Abstracts (Wood, no date, MS); or (c) the Whalemens’ Shipping List (WSL). These last two sources provided information on the itineraries of voyages (e.g. dates of visits to various ports, dates when a vessel was seen or ‘spoken’ at a particular locality at sea) as well as interim and final reports on amounts of oil and baleen obtained (the latter designated as either ‘bone’ or ‘whalebone’). Useful information also came from notes in logbooks referring to other vessels present on the CVI humpback whaling grounds. After identifying a voyage as ‘promising’, the availability of a logbook covering that voyage was determined by reference to Sherman *et al.* (1986), supplemented by indexes of post-1986 acquisitions by the various museums and libraries.

Data recording

Data from logbooks were recorded onto two types of data sheet: one for information on the voyage as a whole, including the vessel specifications, itinerary, time spent on the humpback grounds and other vessels seen there; and one for details of humpback catches and observations. Few documents were read in their entirety. As a rule, it was

Table 1

'Read' sample of voyages that included some effort at humpback whaling in the Cape Verde Islands. s/l = struck but lost. Published returns are from Starbuck (1878) or Hegarty (1959) except as noted. Wood = Wood (no date, MS); WSL = Whalemens' Shipping List. Sp = bbl of sperm oil; wh = bbl of whale oil; bone = lb of baleen.

Rig and Vessel	Year sailed	Home port	Time at CVI	Known humpback takes	Published returns	Sources
Brig <i>Edward</i>	1815	Nantucket	21 Apr.-4 May 1816	1 s/l	173sp	<i>Edward</i> (1815-17, MS)
Brig <i>By Chance</i>	1826	Dartmouth	13-21 Apr. 1827	cow-calf pair struck - cow escaped, calf sank	160sp	<i>By Chance</i> (1826-28, MS)
Schooner <i>E. Nickerson</i>	1853	Provincetown	17 Jan.-17 May 1854	9+6 cows secured, 14+1 cow-calf pair +5 calves s/l, 2 killed/lost	455wh	<i>E. Nickerson</i> (1853-54, MS)
Brig <i>Homer</i>	1855	Nantucket	11 Jan.-? 1856	Definitely humpbacked	107sp, 20wh	<i>Homer</i> (1855-56, MS)
Schooner <i>Walter Irving</i>	1856	Provincetown	17 Jan.-6 Mar. 1857	3 secured, 3 s/l	50wh	<i>Walter Irving</i> (1856-57, MS)
Schooner <i>E. Nickerson</i>	1856	Provincetown	7 Mar.-early May 1857	No catch; humpbacking desultory	65sp, 200wh, 1800bone, sent home 54sp	<i>E. Nickerson</i> (1856-57, MS)
Bark <i>Osceola 3rd</i>	1865	New Bedford	5 Feb.-16 Apr. 1866	2 secured, 2 s/l	312sp, 2wh, sent home 158sp, 70wh (Starbuck); at Boa Vista on 24 Mar. with 70 humpback, trans-shipped at Barbados early May (Wood)	<i>Osceola 3rd</i> (1865-66, MS a; MS b); Wood (no date, MS)
Bark <i>Stafford</i>	1865	New Bedford	20 Jan.-8 Jun. 1866	2+1 calf secured (540gals + 23bbls + ? oil), 1 cow killed/lost, 1 s/l; while mated with <i>Para 1</i> (194gals half-share) +1 cow-calf pair secured, 1 s/l, 1 killed/lost	250sp, sent home 175sp, 48wh (Starbuck); at CVI on 27 May with 100 humpback (Wood)	<i>Stafford</i> (1865-67, MS); Wood (no date, MS)
Schooner <i>Walter Irving</i>	1865	Provincetown	13 Jan.-22 May 1866	Humpbacking in co. with <i>Antarctic</i> (mated) and <i>E.H. Hatfield</i> ; reported at least 1 secured (cow), 2 killed/lost and 1 s/l with <i>Antarctic</i> ; in addition, 1 secured and 1 s/l; returned 80bbls humpback oil	130sp, 12wh, sent home 35sp, 60wh (Starbuck); at Sal 16 Jan. 'waiting for humpbacks to come into the Bay' (WSL); <i>Irving</i> and <i>Antarctic</i> arrived at Boa Vista from Sal on 16 May with 95wh each (<i>Petrel</i>)	<i>Walter Irving</i> (1865-66, MS); <i>Stafford</i> (1865-67, MS); WSL (31 V 1866); <i>Petrel</i> (1865-66, MS)
Bark <i>Solon</i>	1865	New Bedford	28 Jan.-8 May 1866	3 secured, 1 killed/lost, 7 s/l	210sp, 50wh, wrecked and condemned at Barbados Jun. 1866 (Starbuck); at Sal 28 Jan., landed 53 humpback at Barbados 31 May (Wood)	<i>Solon</i> (1865-66, MS); Wood (no date, MS)
Brig <i>Julia</i>	1865	Fayal	At least 11-16 Feb. 1866	Lowered for humpbacks on 16 Feb. at São Nicolau while 'cruising for Sperm Whales'	Not in Starbuck	<i>Julia</i> (1865-66, MS); <i>Osceola 3rd</i> (1865-66, MS a)
Schooner <i>Petrel</i>	1865	New Bedford	3 Feb.-27 May 1866	3 2/5 secured, 1 calf killed/lost and 9 s/l between 3 Apr.-24 May	28sp, 138wh, 450bone (Starbuck); at Boa Vista on 13 Apr. with 40 humpback, ditto 3 May 95 humpback (Wood); at least some of the bone was from CVI humpbacks (<i>Petrel</i>)	<i>Petrel</i> (1865-66, MS); <i>Osceola 3rd</i> (1865-66, MS a; MS b); Wood (no date, MS)
Schooner <i>E.H.Hatfield</i>	1865	Provincetown	Late Jan.-mid Apr. 1866	0	85sp	<i>E.H.Hatfield</i> (1865-66, MS)
Schooner <i>William A. Grozier</i>	1866	Provincetown	9 Feb.-28 Mar. 1867	2 s/l, 1+ cow killed/lost, 1 calf secured (2bbls)	30sp, sent home 124sp	<i>William A. Grozier</i> (1866-67, MS)
Schooner <i>A.L. Putnam</i>	1866	Provincetown	3 Apr.-2 May 1867	Chased humpbacks once in April	160sp, 70wh, sent home 60sp	<i>A.L. Putnam</i> (1866-67, MS)
Schooner <i>Washington Freeman</i>	1868	Fairhaven	12 Feb.-4 Apr. 1869	2 secured	21sp, 312wh, sent home 137sp; took 7 humpbacks off mouth of Congo in 1870	<i>Washington Freeman</i> (1868-70, MS)
Schooner <i>Albert Clarence</i>	1868	Provincetown	26 Dec.-30 Apr. 1869	Chased humpbacks repeatedly at São Nicolau and São Vicente - took some, judging by oil report	107sp; journal states: left CVI on 30 Apr. with 110bbl humpback oil [imputed catch of 4 humpbacks]	<i>Albert Clarence</i> (1868-70, MS)
Schooner <i>Nellie F. Putnam</i>	1869	Provincetown	2 Feb.-2 May 1870	5+1 cow secured (30+18+36+20+14+20bbls), 2+1 calf s/l, 1 killed/lost	No report, withdrawn 1870	<i>Nellie F. Putnam</i> (1869-70, MS)
Bark <i>Perry</i>	1874	Edgartown	12 Mar.-11 Apr. 1876	3 secured, 3 s/l, 1 killed/lost	810sp	<i>Perry</i> (1874-77, MS)
Schooner <i>Clara L. Sparks</i>	1876	Provincetown	17 Jan.-late Mar. 1877	5 secured (24+46+75+15+20bbls), 3 s/l	310sp, 200wh	<i>Clara L. Sparks</i> (1876-77, MS)
Schooner <i>Express</i>	1878	Provincetown	7 Apr.-24 May 1878	7 secured (incl. 1 cow-calf pair), 2 s/l	25sp, 200wh	<i>Express</i> (1878, MS)
Schooner <i>E.H. Hatfield</i>	1880	Edgartown	12 Jan.-21 Mar. 1882	1 secured (12bbls), 1 s/l	260sp, 10wh	<i>E.H. Hatfield</i> (1880-82, MS)
Schooner <i>Golden City</i>	1882	New Bedford	16 Jan.-6 Apr. 1883; 7-14 Feb. 1884	3 secured (1,779gals oil), 2 s/l - mated with <i>Admiral Blake</i>	250sp	<i>Golden City</i> (1882-84, MS)
Brig <i>Eunice H. Adams</i>	1885	Edgartown	28 Jan.-15 Apr. 1886	1 secured, 5 s/l, plus assisted shore crews in securing 1 and striking/losing 1 (also mated with <i>C.W. Morse</i>)	375sp	<i>Eunice H. Adams</i> (1885-87, MS)
Bark <i>George and Mary</i>	1888	New Bedford	Brief visit to São Nicolau 3-7 Mar. 1891	Desultory effort humpbacking	1150sp	<i>George and Mary</i> (1888-1891, MS)
Schooner <i>Adelia Chase</i>	1901	New Bedford	27 Feb.-30 Apr. 1902	1 secured	305sp	<i>Adelia Chase</i> (1901-02, MS)

determined by rapid scanning if and when the vessel visited the CVI. Daily entries for the period(s) on the grounds were checked for references to humpback whales. Most logbook keepers made clear the distinction between humpback and other whales although in some instances it was necessary for the reader to infer the identity of the whales. Pilot whales were always called 'blackfish.' Whenever sperm whales were seen on the humpback grounds, the logbook writers seem to have specified them as such. 'Finbacks' mentioned in this region could have been fin whales (*Balaenoptera physalus*), sei whales (*B. borealis*) or Bryde's whales (*B. edeni*) (cf. Mead, 1977). Blue whales (*Balaenoptera musculus*), killer whales (*Orcinus orca*) and assorted other kinds of cetaceans (e.g. 'grampus', probably *Balaenoptera acutorostrata*; 'cowfish', possibly *Tursiops* sp.; dolphins or 'porpoises', probably mostly small delphinids) were also mentioned in the logbooks while vessels were in the CVI (see Reiner *et al.*, 1996; Hazevoet and Wenzel, 2000 for information on the species known to occur there).

The whalemens who kept logbooks presented the reader with an often bewildering array of place names, which makes the work of determining where a vessel was at any given time painstaking at best and exasperating at worst. Legibility of the manuscripts was highly variable and so was the level of detail provided by the writers. It was often difficult to match the names given to landmarks in the logbooks to present-day Portuguese place names. All too frequently, nothing was provided beyond the name of the island. In many cases reference was made to the site where the vessel anchored for the night, and it was either stated or implied that the intervals between anchorings were spent cruising, with a lookout kept for whales. At times the vessel would remain anchored while the boats were lowered to chase whales in nearby waters. The logbooks often indicated approximately where a whale was towed for processing; it could only be inferred that the whale therefore had been killed within a short distance of that site.

Data management

A computer database was established with two components. The first was a summary of each voyage, including: vessel name; voyage number assigned by us; port and date of sailing; ground(s) worked; and notes about the legibility, usefulness or other characteristics of the log. The second contained a summary of all relevant records from each log, including: vessel and voyage number; record type; date; location and (where relevant) number of whales seen, struck or killed. Record types examined here were categorised as either 'whale' (information about sightings of, or attempts to kill, whales), or 'no whales' (records in which a log explicitly referred to the absence of whales in a particular location). Other information about where the vessel was on a particular day, shipments of whale oil, processing of whales, other vessels and miscellaneous subjects unrelated to whale encounters *per se* were included in the database but not used in the analyses. Reports of 'lowering for whales', or of whales seen but with no indication of how many were present, were also recorded but not used in the analyses.

Records of whales were further broken down into five categories: (1) 'taken number' (a specific number of whales reported as killed and secured); (2) 'taken barrels' (records in which the oil yield of one or more whales was given, in barrels); (3) 'struck' (whales chased and struck with a harpoon or bomb lance but not killed, or killed but not secured); (4) 'seen number' (a specific number of whales reported as sighted but not struck); and (5) 'seen category'

(records in which sightings of whales were not associated with a number but rather with a descriptive term such as 'few' or 'many').

With regard to the latter category, the various descriptive terms found in the logs were grouped for simplicity into three categories, as follows: (1) 'many' = *many, a school, plenty, great number, a pod, a gam*; (2) 'several' = *a number, several, some, more, saw humpbacks, chased humpbacks*; and (3) 'few' = *few*. For the purpose of analysis, an 'average' (and of necessity, arbitrary) number was assigned to each of these categories, as follows: 'many' equalled ten whales; 'several' equalled four whales; and 'few' equalled two whales. The results presented here are subject to that caveat.

Location information associated with whale reports fell into two categories. In many cases, an exact location (such as a bay or a latitude and longitude) was given; in the database, these were termed 'certain' locations. In other cases, no exact location was given but a general location could be inferred from preceding or subsequent log entries; in the database, these were termed 'inferred' locations. Cases in which a lack of information precluded assignment of even an inferred location were treated as 'no location'.

Estimation of catches

Mitchell and Reeves (1983) used two methods to estimate humpback catches in the West Indies from similar data to those obtained in the present study: (1) they applied the average catch per vessel-season (7 humpbacks) from the voyages for which they had complete logbook data, to all voyages known (or presumed) to have whaled for humpbacks in the West Indies; (2) they used the average amount of oil obtained from humpbacks reported in their logbook sample (25bbl) to convert whale oil returns (from Starbuck, 1878; Hegarty, 1959) into estimated catches¹. Mitchell and Reeves (1983) recognised three categories of humpback voyages: (1) those for which the logbook was read — their 'read' sample; (2) those where the vessel was reported in another vessel's logbook to have been present on the grounds and chasing humpbacks — their 'sighted' sample; and (3) those identified solely on the basis of circumstantial evidence, namely Provincetown as port of origin, sailed between 1866-87, no baleen in the published returns (so as to avoid including right whale catches) and a departure date between October and March with return to port before the following winter — their 'extrapolation' sample. Kills from the three categories of voyages were summed by year, using the midpoints of the ranges between 'oil yield' estimates and 'catch-per-voyage' estimates for the 'sighted' and 'extrapolation' samples (see Mitchell and Reeves, 1983: their table 12).

In the present paper, a similar approach was used although with some significant modifications. Unlike in Mitchell and Reeves (1983), the goal here was not to estimate 'initial' population size, so no attempt was made to estimate total removals by factoring in hunting loss. Instead, secured catches were compiled for the 'read' logbook sample by summing the numbers of whales recorded in the logbooks as killed, regardless of whether they were eventually secured (Table 1). Calves that were harpooned, or whose mothers were harpooned, were counted as dead whales. In addition to the known kill from the 'read' sample, catches of humpback

¹Using an entirely different dataset and a different method, Best (1987) estimated the average oil yield of humpbacks as 24.4bbl (CV = 0.110), apparently applying to all oceans. In the present study, 19 humpbacks from the CVI for which oil yields were recorded in the logbooks produced an average of 25.5bbl (SD 14.1, range = 11-75).

whales were estimated for a 'sighted vessel' sample (Table 2). This sample was identified on the basis of information contained in logbooks, supplemented by information from Townsend and Watson (no date, MS). To estimate catches for the 'sighted vessel' sample, an average yield of 25bbl/whale (see Footnote 1) was applied to the whale oil returns in Starbuck (1878) or Hegarty (1959). In some instances, additional information on oil returns was available from another source.

Participation in the CVI humpback fishery was more heterogeneous than was the case in the West Indies; Provincetown schooners were prominent but not necessarily as predominant in the CVI as they were in the West Indies. Barks engaged more frequently in CVI humpbacking than in West Indies humpbacking. Because of the difficulty of identifying a set of characteristic features of CVI humpbacking voyages, no extrapolation was attempted beyond the 'read' and 'sighted vessel' samples of voyages. However, data contained in Wood (no date, MS) and the WSL made it possible to create an 'extrapolation' sample of sorts. Those sources provided occasional information on localities and amounts of oil and bone on board for most of the American fleet. A number of voyages were thus identified in which there was a high or reasonable likelihood of some CVI humpbacking to have taken place (Table 3). Humpback catches for such voyages were estimated in the same way as for the 'sighted vessel' voyages.

It was not always possible to determine whether whale oil, and even to some extent baleen ('whalebone' or 'bone'), obtained in the southeastern North Atlantic was from right whales (Cintra Bay Ground) or humpbacks (CVI). Various approaches were used to derive inferences, but occasionally no non-arbitrary basis could be found for deciding how to allocate or pro-rate a particular quantity of product. In addition, the proximity of the CVI to the humpback whaling grounds in the Gulf of Guinea (south to the mouth of the Congo) created the potential for misallocating humpback oil or whale oil taken in the tropical and sub-tropical eastern Atlantic. Humpbacking on the coast of Africa was conducted mainly between June and October and was therefore generally out of phase with that in the CVI. Destinations given in itineraries for the Gulf of Guinea grounds included 'St Thomas' (São Tome), Anabon (Annobon, or Pagalu; see Aguilar, 1985), Congo River, Kabenda, Bissau and Loando.

The notes in Wood (no date, MS) frequently posed interpretive problems. For example, the bark *R.L. Barstow* of Nantucket, which humpbacked at the CVI in early 1866 (Table 2), also may have done so in 1863-65. Wood reported its location and products on board as follows: Boa Vista 3 March 1863, 80 sperm; ditto 8 April, 100 sperm; no location or date, 25-30 whale; CVI no date, 80 sperm; CVI 12 June, 70 sperm, 100 'Hump Back'. In the following winter (1864) of the same cruise: Boa Vista before 29 February and trans-shipped 125 sperm; off Bissau, W.C. [West Coast] Africa, 5 May, 60 whale. Finally, in the third winter (1865) of the same cruise: Boa Vista 3 May, having taken 50 sperm and 200 'Humpback oil' and 1200lb 'Bone' during the previous 90 days (reportedly 370 sperm, 450 Humpback and 2000 Bone 'all told') (Wood, no date, MS). Starbuck (1878) gave the returns for this three-year voyage as 360 sperm, 556 whale and no bone. It seems likely that some of the whale oil and possibly the baleen came from CVI whales, but the visit to the coast of Africa just prior to the Gulf of Guinea/Congo humpbacking season in 1864 causes uncertainty and suggests that some portion of the catch could have come from a Southern Hemisphere humpback whale population.

A recurrent problem in the Wood abstracts (as well as the WSL) is that oil other than sperm oil was inconsistently identified as either whale, humpback or blackfish oil. Not infrequently, Wood applied two or three of these terms to the same quantity of oil within a single abstract of a voyage. For example, the Provincetown schooner *S.R. Soper* obtained at least 125bbl of whale oil from right whales in Cintra Bay in 1856 (Reeves and Mitchell, 1986) and another 25bbl possibly from a humpback whale at the CVI (Table 3). Wood listed the return as 150bbl of blackfish oil, which is implausible in any event as individual voyages rarely returned more than 100bbl of blackfish oil (Clark, 1887a).

Comparison with the West Indies

Since the methods and data reporting format used here were virtually identical to those employed by Reeves *et al.* (2001) for 19th century West Indies humpback whaling, it was possible to make a crude comparison of whale densities (encounter rates) at the CVI and West Indies. Although effort was impossible to quantify with any precision, the number of days in which each vessel was known to have been present on the respective whaling grounds was used as a proxy for effort. This assumed that any biases, while undoubtedly differing from vessel to vessel, were not significantly different between the two grounds. There is no way to assess the validity of this assumption.

Encounter rates were calculated by dividing the sum of total reported takes and strikes plus estimated whales sighted, by the number of days that each vessel was known to have spent on the whaling ground. An overall figure for all humpback whale records (takes, strikes and sightings combined) was also calculated in the same way.

These rates were calculated for the Cape Verde Islands with no distinction among islands. For the West Indies, three regions were examined separately: (1) the southernmost area, consisting of Trinidad, Tobago, the Gulf of Paria and the coast of Venezuela; (2) the region from Guadeloupe to St Vincent and the Grenadines, including Barbados (this was the area found by Reeves *et al.*, 2001 to have had the highest number of humpback whale records in the West Indies); and (3) the Dominican Republic and Puerto Rico.

RESULTS

Summary of the data

The data described here came primarily from 20 'read' voyages to the CVI by 18 different vessels (Table 1). The earliest cruise was in 1815-16, the latest in 1901-02. Ports of departure for these voyages (all of them in Massachusetts except as otherwise stated) included: Dartmouth (1); Edgartown (3); Nantucket (2); New Bedford (7); Provincetown (6); and Fayal, Azores (1). A total of 452 records was used for the analysis of distribution and occurrence. This included 396 records of whales and 56 records of 'no whales'.

The study area was divided into eight regions by major island. These included Boa Vista, Brava, Maio, Sal, Santa Luzia, Santo Antão, São Nicolau and São Vicente. The eight regions are listed in Table 4, with a summary of the number of records available for each. The largest number of records came from São Nicolau, Sal and São Vicente (109, 105 and 95, respectively). The fewest (2 records) came from the island of Maio. A ninth island in the CVI group, São Tiago, had no whale-related records.

Table 2

'Sighted vessel' sample of voyages that included some effort at humpback whaling in the Cape Verde Islands, or were in the CVI when other vessels were humpback whaling there. Published returns are from Starbuck (1878) or Hegarty (1959) unless otherwise noted. Wood = Wood (no date, MS); WSL = Whalemens' Shipping List. Sp = bbl of sperm oil; wh = bbl of whale oil; bone = lb of baleen.

Rig and Vessel ¹	Year sailed	Home port	Time at CVI	Known humpback takes	Published returns	Sources	Est. catch
Schooner <i>Antarctic</i>	1852	Provincetown	At least 11 Mar. 1852		240sp, 50wh; at 17°N, 20°24'W on 11 Mar. with 50 humpback in 40 days out	<i>R.L. Barstow</i> (1851-53, MS)	2
Bark <i>Willis</i>	1854	Mattapoisett	At least 8-9 Mar. 1854	1 struck/lost on 9 Mar.	363sp, 24wh	<i>E. Nickerson</i> (1853-54, MS)	1
Brig <i>September</i>	1853	Orleans	At least 16 Feb.-at least 14 Apr. 1854	1 (cow) struck on 16 Feb., 1 secured on 24 Feb., another on 19 Mar., 1 struck on 22 Mar. and another (taken or just struck?) on 14 Apr.	25sp 'at last report'	<i>E. Nickerson</i> (1853-54, MS)	3 or 4
Schooner <i>Watchman</i>	1855	Nantucket	At least 14 Feb.-31 May 1856	Apparently took many CVI humpbacks	530wh (Starbuck); Boa Vista 14 Feb. 125wh, CVI 20 Mar. 140wh, São Tiago 29 Mar. 250wh, no date 400wh, 31 May master drowned at Boa Vista, returned with 550wh (Wood)	<i>Homer</i> (1855-56, MS); Wood (no date, MS)	22
Schooner <i>Hamilton</i>	1855	Nantucket	At least Feb. 1856	Definitely humpbacking	No information	<i>Homer</i> (1855-56, MS)	Prob. some
Schooner <i>William P. Dolliver</i>	1855	Nantucket	At least Feb. 1856	Definitely humpbacking; s/l at least 2	No information	<i>Homer</i> (1855-56, MS)	Prob. some
Bark <i>Osceola</i> (uncertain which one)	1854	New Bedford	Feb. 1856	Unclear if humpbacking	Uncertain (depends which of 3 vessels named <i>Osceola</i>)	<i>Homer</i> (1855-56, MS)	?
Brig <i>Medford</i>	1856	Orleans	At least 24 Mar. 1857		55sp, 285wh, 2100bone	<i>E. Nickerson</i> (1856-57, MS)	0
Brig <i>Parana</i>	1856	Sag Harbor	At least 24 Mar. 1857		450wh, 4900bone, sent home 380sp	<i>E. Nickerson</i> (1856-57, MS)	0
Schooner <i>Silver Cloud</i>	1856	New London	At least 3 Apr.-Jun. 1857	Successful whaling for right whales in Cintra Bay in 1857 or 1858 (see Reeves and Mitchell, 1986, table 4) but probably also took at least 1 humpback at CVI in 1857	No report, wrecked at sea Sep. 1862 (Starbuck); at Boa Vista 3 Apr. 1857 with 130wh (<i>E. Nickerson</i>), at CVI May with 150wh (Wood)	<i>E. Nickerson</i> (1856-57, MS)	1
Bark <i>Spartan</i>	1855	Provincetown	At least 8-24 Mar. 1857		450sp, 450wh, 4000bone	<i>E. Nickerson</i> (1856-57, MS)	0
Schooner <i>Sea Witch</i>	1856	New London	At least 24 Mar.-9 Jun. 1857		130wh, 600bone (Starbuck); no position 1 Dec. 60wh, Boa Vista 29Mar 75wh, CVI 9 Jun. 120wh (Wood)	<i>E. Nickerson</i> (1856-57, MS); Wood (no date, MS)	2 or 3
Schooner <i>Watchman</i>	1856	Nantucket	At least 24 Mar.-9 Jun. 1857	1 s/l on 26 Mar.; some humpbacks apparently secured judging by Wood data	44sp, 386wh, 1350bone (Starbuck) - note that some of production was from Cintra Bay right whales (Reeves and Mitchell); at Canaries 11 Nov. 1856 clean, no position 1 Dec. 60wh, Boa Vista 29 Mar. 1857 75wh, CVI 9 Jun. 120wh; total returns given by Wood as 150wh, 100 humpback, 40sp, plus sent home 130wh, 1500bone (Wood)	<i>E. Nickerson</i> (1856-57, MS); Wood (no date, MS); Reeves and Mitchell (1986)	4
Schooner <i>Montezuma</i>	1857	Provincetown	At least 11 Mar. 1857		7sp, 150wh	<i>E. Nickerson</i> (1856-57, MS)	6
* Schooner <i>E.H. Hatfield</i>	1861	Provincetown	At least 4 Mar.-22 Apr. 1862	8 secured (apparently)	181sp, 239wh, sent home 50sp	Townsend and Watson (no date, MS)	8
Bark <i>Willis</i>	1865	New Bedford	At least 18 Jan.-19 Feb. 1866		Sent home 408sp, 180wh, 800bone (condemned at Fayal 1866) (Starbuck); at CVI 25 Jan. clean, Sal 10 Feb. 25sp, 20wh, 27 May landed 110wh at Barbados (Wood)	<i>Osceola 3rd</i> (1865-66, MS a); <i>Solon</i> (1865-66, MS); <i>Stafford</i> (1865-67, MS); <i>Walter Irving</i> (1865-66, MS); Wood (no date, MS)	4
Bark <i>Thomas Winslow</i>	1865	New Bedford	6 Feb.-5 May 1866	1 secured 18 Mar. (31bbls; <i>Petrel</i>), 1 (cow) secured 3 Apr. (40bbls, in co. with <i>Petrel</i>), 1 secured 10 Apr. (22bbl, in co. with <i>Petrel</i>), 1 s/l 13 Apr. (<i>Petrel</i>), 1 secured 27 Apr. (20bbl; <i>Petrel</i>), 1 secured and 1 killed/lost 4 May (<i>Petrel</i>)	40sp, 210wh, 500bone, sent home 133sp, 37wh, 450bone (Starbuck); at Boa Vista 21 Mar. with 160sp, 25 humpback, ditto 8 May 90 humpback since last report (Wood); note that at least some of the bone was from CVI humpbacks (<i>Petrel</i>)	<i>Osceola 3rd</i> (1865-66, MS a; MS b); Wood (no date, MS); <i>Petrel</i> (1865-66, MS)	5

cont...

Table 2 continued.

Rig and Vessel ¹	Year sailed	Home port	Time at CVI	Known humpback takes	Published returns	Sources	Est. catch
Schooner <i>Eleanor B. Conwell</i>	1864	Provincetown	10 Feb.-12 Mar. 1866	1 killed/sank on 26 Feb. (<i>Petrel</i>), 1 killed/sank on 27 Feb. (<i>Osceola</i>)	63sp, 25wh, sent home 40sp, 180wh	<i>Osceola 3rd</i> (1865-66, MS a); <i>Petrel</i> (1865-66, MS); Walter Irving (1865-66, MS)	2 or 3
Bark <i>R.L. Barstow</i>	1865	Nantucket	At least 5 Feb.-26 May 1866 [later in cruise visited So. Atlantic grounds (Wood)]	Cow-calf secured on 22 Feb. (<i>Petrel</i>), 1 secured (small) on 23 Feb. (<i>Osceola</i>), 1 s/l on 23 May (<i>Petrel</i>)	400sp, 400wh (Starbuck); at Boa Vista 5 Feb. with 80sp, ditto 10 Mar. 85sp, 25humpback, later (prior to 1 Jul.) no position with 90sp, 200 humpback	Wood (no date, MS); <i>Petrel</i> (1865-66, MS); <i>Solon</i> (1865-66, MS); <i>Osceola 3rd</i> (1865-66, MS a)	2 to 8
Schooner <i>Louisa A.</i>	1865	Boston	9 Feb.-26 May 1866; Boa Vista on 9 Feb., 'arrived to humpback' (<i>Petrel</i>); at São Vicente 20 Feb. 1867 (Wood)	1 secured (small) on 24 Mar. (<i>Osceola</i>) (this was a 'bull' acc. to <i>Petrel</i>); Capt Freeman was killed while fast to a humpback at Maio sometime before 21 Apr. (<i>Petrel</i>); 3 secured 10-17 May (one was 18bbl; <i>Petrel</i>)	220sp, sent home 112sp, 175wh (Starbuck); shipped 75bbl whale oil on <i>Fredonia</i> from Fayal prior to Aug. 1866 (Wood); made 320sp, 380wh all told this cruise (Wood)	<i>Osceola 3rd</i> (1865-66, MS a); <i>Petrel</i> (1865-66, MS); Walter Irving (1865-66, MS)	4 to 7
Bark <i>Louisa</i>	1865	New Bedford	At least 17 Feb.-23 Mar. 1866	Definitely humpbacking	470sp, sent home 318sp, 36wh	<i>Osceola 3rd</i> (1865-66, MS a; MS b)	2
Bark <i>Leonidas</i>	1865	New Bedford	At least 27 Jan. -8 May 1866	1 small finback on 14 Feb. (in co. with <i>Solon</i>), 1 on 25 Mar. (apparently took at least 1 more judging by oil returns)	180sp, 270wh, 1000bone, sent home 95sp, 36wh (Starbuck); at São Nicolau no date clean, ditto 21 Apr. 60 humpback, 29 May at Barbados 80 humpback (Wood)	<i>Solon</i> (1865-66, MS); <i>Stafford</i> (1865-67, MS); Wood (no date, MS)	2 or 3
Schooner <i>Varnum H. Hill</i>	1865	Provincetown	At least 27 Jan.- 5 Feb. 1866		160sp, 90wh	<i>Solon</i> (1865-66, MS); <i>Stafford</i> (1865-67, MS)	4
Schooner <i>Admiral Blake</i>	1865	Sippican	At least 2 Feb.-30 May 1866	Definitely humpbacking; arrived São Nicolau 6 Feb., mated with <i>Stafford</i> to humpback, remained in CVI until 30 May (likely that entire 160bbl humpback oil was from CVI)	130sp, 150wh (Starbuck); São Vicente 2 Feb. clean, ditto 28 Mar. 35sp, São Nicolau 6 May 90sp, São Vicente 27 May 150 unsp., 16 Jul. no position 25sp, 160 humpback (Wood)	<i>Solon</i> (1865-66, MS); <i>Stafford</i> (1865-67, MS); Wood (no date, MS)	6
Schooner <i>S.E. Lewis</i>	1865	Boston	At least 13 Feb. 1866		70sp, sent home 131sp	<i>Solon</i> (1865-66, MS)	0
Schooner <i>Mary E. Curren</i>	1865	Provincetown	16 Jan.-at least late Apr. 1866	1 on 26 Apr.	317wh, sent home 507sp (Starbuck); at CVI 17 Mar. with 175wh (WSL)	<i>Stafford</i> (1865-67, MS); Walter Irving (1865-66, MS); WSL	7 to 13
Schooner <i>Rising Sun</i>	1865	Provincetown	At least 2 Feb.-17 Mar. 1866		40sp, 249wh (Starbuck); at CVI 17Mar with 20 unsp. (WSL)	<i>Stafford</i> (1865-67, MS); WSL	10
Schooner <i>Antarctic</i>	1865	Provincetown	At least 22 Jan.-22 May 1866	Definitely humpbacking (in co. with <i>Walter Irving</i>) using bomb lances (see <i>Irving</i> entry in Table 1)	25sp, 40wh, sent home 145sp, 95wh (Starbuck); at CVI 25 Apr. with 75wh (WSL); arrived at Boa Vista from Sal on 16 May with 95wh (<i>Petrel</i>)	<i>Osceola 3rd</i> (1865-66, MS a); <i>Walter Irving</i> (1865-66, MS); <i>S.R. Soper</i> (1865-66, MS); WSL; <i>Petrel</i> (1865-66, MS)	4 to 6
*Schooner <i>Para</i>	1865	Salem	22 Feb.-8 Jun. 1866	1 on 20 Mar. (in co. with <i>Stafford</i>), 1 s/l on 21 Mar., took 1 on 27 Mar., killed/lost 1 on 15 Apr. (in co. with <i>Stafford</i>), killed calf and s/l cow on 21 Apr. (in co. with <i>Stafford</i>), 1 on 29 Apr., took 1 alongside that had been killed by <i>Stafford</i> on 17 May	140wh, sent home 200 humpback (Starbuck) in Nov. 1866 from Barbados (Wood); at São Vicente 7 Mar. with 20 humpback, 19 May with 150 humpback (Wood)	<i>Stafford</i> (1865-67, MS); Wood (no date, MS)	8
Bark <i>St Elizabeth</i>	1866	Boston (Turks Island? <i>fide</i> logbooks of <i>Petrel</i> and <i>Walter Irving</i>)	At least 4-20 Apr. 1866		No returns; condemned (Starbuck); at Boa Vista 15 Apr. clean (<i>Petrel</i>)	<i>Stafford</i> (1865-67, MS); <i>Petrel</i> (1865-66, MS); <i>Walter Irving</i> (1865-66, MS); <i>Osceola 3rd</i> (1865-66, MS a; MS b)	0
Schooner <i>Mary E. Simmons</i>	1865	Provincetown	At least 17 Mar.-29 May 1866		51sp, 252wh, sent home 280sp (Starbuck); at CVI 17 Mar. and 15 May with 150wh	<i>Stafford</i> (1865-67, MS); WSL	6 to 10

Table 2 continued.

Rig and Vessel ¹	Year sailed	Home port	Time at CVI	Known humpback takes	Published returns	Sources	Est. catch
Schooner <i>Sassacus</i>	1865	Provincetown	At least 19 Jan.-23 May 1866		120sp, 45wh, sent home 60sp, 175 humpback	<i>Stafford</i> (1865-67, MS); <i>William A. Grozier</i> (1866-67, MS); <i>Walter Irving</i> (1865-66, MS)	7
Schooner <i>Quickstep</i>	1865	Provincetown	At least 17 Mar.-25 May 1866	Cow/calf on 25 May	80sp, 275wh (Starbuck); at CVI on 17 Mar. with 50wh (WSL)	<i>Stafford</i> (1865-67, MS); WSL	11
Schooner <i>Susan N. Smith</i>	1865	Boston	At least 22 Jan.-Apr. 1866, Feb. 1867		240sp; at CVI 25 Jan. 1866 clean, São Vicente 20 Apr. 120sp, São Nicolau 20 Oct. 125sp (240sp all told); São Vicente 20 Feb. 1867 (Wood)	<i>Stafford</i> (1865-67, MS); <i>Walter Irving</i> (1865-66, MS)	0
Ship <i>Comm. Morris</i>	1865	New Bedford	At least 21 Jan. -Apr. 1866; 6-9 Mar. 1867	1 secured (45bbl) in 1866	850sp, 70wh, sent home 1810sp, 30wh	<i>Osceola 3rd</i> (1865-66, MS a); <i>Stafford</i> (1865-67, MS); <i>William A. Grozier</i> (1866-67, MS); Wood (no date, MS)	1 to 3
Schooner <i>Montezuma</i>	1866	Provincetown	At least 2 Mar. 1867		160sp, 35wh	<i>William A. Grozier</i> (1866-67, MS)	1
Schooner <i>Quickstep</i>	1866	Provincetown	At least 25 Mar.-19 Apr. 1867		200sp, 200wh; at CVI 19 Apr with 200 humpback (WSL 25(14): 4VI 1867)	<i>William A. Grozier</i> (1866-67, MS)	8
Schooner <i>Edith May</i>	1866	Wellfleet	At least 27 Feb. 1867		239sp, sent home 80sp	<i>William A. Grozier</i> (1866-67, MS)	0
Schooner <i>William Martin</i>	1866	Boston	At least Feb. 1867	Evidently visited CVI with intention of humpbacking: at São Vicente, no date, 'with many other whalers, waiting for the weather to moderate. Very few humpbacks about the Islands and but little oil had been taken' (WSL), at Bravo 12 Feb. 20sp (WSL), seen blackfishing at Santo Antão 21 Feb, at Barbados 25 Apr. 50sp (WSL)	225sp	<i>William A. Grozier</i> (1866-67, MS)	0
Schooner <i>A.H. (Abbie) Brown</i>	1867	Provincetown	At least 26 Jan.-7 Feb. 1869		280sp, 80wh, sent home 45sp	<i>Albert Clarence</i> (1868-70, MS)	3
Bark <i>A.R. Tucker</i>	1868	New Bedford	At least 24 Feb.-29 Apr. 1869		147sp, sent home 108sp	<i>Albert Clarence</i> (1868-70, MS)	0
Schooner <i>S.A. Paine</i>	1867	Provincetown	At least 26 Jan. 1869		180sp, 180wh, sent home 114sp	<i>Albert Clarence</i> (1868-70, MS)	?
Schooner <i>Edith May</i>	1867	Wellfleet	At least 26 Jan.-30 Apr. 1869	Much of season in company with <i>A. Clarence</i> , which was definitely humpbacking	260sp, 85wh, sent home 85sp	<i>Albert Clarence</i> (1868-70, MS)	3
Schooner <i>B.F. Sparks</i>	1876	Provincetown	At least mid Mar. 1877	1 secured on 17 Mar.	310sp, 150wh	<i>Clara L. Sparks</i> (1876-77, MS)	6
Schooner <i>William Wilson</i>	1876	Marion	At least 15 Feb. 1877		85sp, 125wh	<i>Clara L. Sparks</i> (1876-77, MS)	5
*Schooner <i>E.H. Hatfield</i>	1876	Provincetown	At least 26 Feb. 1877	1 secured on 26 Feb.	No data	Townsend and Watson (no date, MS)	1
Schooner <i>Crown Point</i>	1882	Provincetown	1 Feb.-at least 14 Mar. 1883	1 before 22 Feb. (19bbl), 1 on 7 Mar. (35bbl - 90bbl total to date), 1 on 14 Mar.	140sp, 100wh	<i>Golden City</i> (1882-84, MS)	4
Schooner <i>Admiral Blake</i>	1882	Marion	1 Feb.- 2 Mar. 1883	1 s/l on 23 Feb. (in co. with <i>Golden City</i>), s/l cow-calf pair on 28 Feb. (in co. as above)	365sp, 30wh	<i>Golden City</i> (1882-84, MS)	1
Schooner <i>M.E. Simmons</i>	1883	New Bedford	At least 7 Feb. 1884	Master aboard <i>Golden City</i> whilst humpbacks being chased in Calm Bay, São Vicente	635sp	<i>Golden City</i> (1882-84, MS)	?
Schooner <i>Adelia Chase</i>	1882	New Bedford	At least 13 Feb. 1884		380sp, 230wh	<i>Golden City</i> (1882-84, MS)	?
Schooner <i>Chas. W. Morse</i>	1883	New Bedford	At least 10 Feb.-11 Mar. 1886	Definitely humpbacking (mated with <i>E.H. Adams</i>), helped process 1 on 17 Feb., struck 1 on 22 Feb.	410sp, 195wh	<i>Eunice H. Adams</i> (1885-87, MS)	1 to 8
Schooner <i>Mary E. Simmons</i>	1889	New Bedford	At least 3-7 Mar. 1891	Desultory effort humpbacking	1580sp	<i>George and Mary</i> (1888-91, MS)	0

¹ Asterisk (*) indicates that Townsend and Watson (no date, MS) recorded at least one humpback kill in the CVI.

Table 3

Voyages suspected of having included some effort at humpback whaling in the Cape Verde Islands. Inferences based mainly on evidence in Wood (no date, MS) or Whalemens's Shipping List (WSL). Published returns are from Starbuck (1878) or Hegarty (1959) unless otherwise noted. Wood = Wood (no date, MS); WSL = Whalemens's Shipping List. Sp = bbl of sperm oil; wh = bbl of whale oil; bone = lb of baleen.

Rig and Vessel	Year sailed	Home port	Time at CVI	Basis for inference	Published returns	Est. catch
Bark <i>Franklin</i>	1853	Provincetown	?	Statement in Starbuck (1878): 'Lost on Isle of Sal, Cape de Verdes; saved 140 barrels whale'.	-	6
Brig <i>Amelia</i>	1854	Sandwich	At least 8 Mar. 1855	Sailed for 'Atlantic' on 27 Jul., called at São Tiago 8 Mar. 1855 with 325wh on board, spoke 28 Aug. NE of Bermuda	265wh [330 'Hump Back Whale oil' (Wood)], after 13mo. cruise	13
Schooner <i>Antarctic</i>	1854	Provincetown	At least 19 Mar.-10 Apr. 1855	Called at CVI 19 Mar. with 25sp, 50 'B.F.' on board; again 10 Apr. with 25sp, 120wh	No information	5
Bark <i>Osceola</i>	1854	New Bedford	At least 11 Feb.-1 Apr. 1856	At Sal 11 Feb. with 20sp, 45wh, having reported previously from Fayal 7 Oct. with no oil; at CVI 20 Mar. with 70sp, 70wh; at São Nicolau 1 Apr. with 50sp, 120wh; at Fayal 10 Jun. with 80sp, 170wh	198sp, 171wh, 400bone, sent home 702sp [200sp, 160wh, 400bone (Wood)]	7
Brig <i>Amelia</i>	1854	Sandwich	At least Mar. 1855	At São Tiago 8 Mar. 325wh	265wh [330 humpback (Wood)]	13
Brig <i>Amelia</i>	1855	Sandwich	At least Mar. 1856	Sailed for 'Atlantic' on 16 Oct., called at CVI in Mar., returned home 2 Sep. 1856	Returned 'clean' (no catch) [23 'Hump Back' sold during voyage (Wood)]	1
Schooner <i>S.R. Soper</i>	1855	Provincetown	Late Mar./Apr. 1856	After right whaling in Cintra Bay (see Reeves and Mitchell, 1986, table 4), master killed by a whale at CVI <i>ca</i> late Mar.-Apr. 1856	42sp, 152wh [45sp, 150 'B.F. oil' (Wood)]	1
Brig <i>Amelia</i>	1855	Sandwich	Mar. 1856	At CVI Mar., no report; sold 23bbl humpback oil during voyage	Clean	1
Bark <i>Benjamin Franklin</i>	1855	Beverly/Fall River	? Possibly Jan.-Mar. 1856	At São Vicente 19 Dec. 1855 'bound HumpBack', sailed from ditto 26 Dec., 1 Jan. 1856 sailed from São Tiago with 40sp, arrived São Tome 17 Apr., at 38°N 2 Jun. with 200wh (apparently humpbacked mainly or only in Gulf of Guinea? Wrong season)	16sp, 169wh	?
Bark <i>Rothschild</i>	1855	Orleans	At least mid-Apr. to late May 1856	Cintra Bay 8 Feb. 40wh, no location 25 Mar. with 120wh, CVI 24 Apr. with 260wh, ditto 22 May with 300wh, Fayal 5 Jul. with 335wh; also see Reeves and Mitchell (1986, table 4)	325sp, 380wh	7
Schooner <i>William Martin</i>	1856	Orleans	At least 16 Mar.-3 Jun. 1856	At Cintra Bay 8 Mar. 1856 clean, ditto 16 Mar., Madeira Bay no date 60 unspecified, CVI 22 May 145unspec., 800bone, Sal 3 Jun. 200unspec.	Not in Starbuck [returned 189wh, 800bone in 8mo. (Wood)]	2
Bark <i>Rothschild</i>	1857	Orleans	At least early Apr. 1858	At Cintra Bay 18 Jan. 1858 clean, CVI 6 Apr. with 30sp, 60 humpback; also see Reeves and Mitchell (1986, table 4)	46sp, 64wh	2
Brig <i>Eschol</i>	1857	Provincetown	At least 16 Feb. 1858	After right whaling in Cintra Bay, arrived CVI 16 Feb. with 210sp, 75wh, returned home 3mo. later with 210sp, 140wh, 300lb bone	200sp, 140wh, 300bone	3
Brig <i>Medford</i>	1858	Orleans	?	At Tenerife 25 Nov., oil not reported; next at Barbados 24 May 1859 with 240 humpback on board	25sp, 224wh, sent home 119sp	Poss. as many as 9
Schooner <i>Watchman</i>	1858	Nantucket	At least 5 Apr. 1859	At Boa Vista 5 Apr. 400wh	563wh	12 to 17
Schooner <i>Watchman</i>	1859	Nantucket	At least 30 Jan.-30 May 1860	At CVI 30 Jan. with 70wh, 700bone, São Nicolau 20 Apr. 270bbls unspecified, ditto 30 May 321humpback, no position 8 Aug. 50sp, 400 humpback	65sp, 430wh [arrived with 65sp, 360wh, sent home 70wh, 700bone (Wood)]	16
Bark <i>Acorn</i>	1859	Provincetown	At least 15 Apr. 1860	50 wh on board at CVI within 4mo of sailing	80sp, 70wh	3
Bark <i>Rothschild</i>	1860	Orleans	At least 20 Feb.-30 May 1860; Apr. 1861	At CVI 20 Feb. clean, ditto 30 Mar. with a whale alongside, São Nicolau 20 Apr. with 190bbl unspec., ditto 30 May with 300 humpback, halfway between Azores and Bermuda 24 Jul. with 350 humpback; at CVI 22 Apr. 1861 120sp, 400wh, Fayal 1 Jul. 125sp, 455wh	30sp, 706wh, sent home 110sp [130sp, 760 humpback (Wood)]	12 (1860); 18 (1861)
Schooner <i>Watchman</i>	1860	Nantucket	1861	At Cintra Bay Jan. 1861 clean, CVI no date 150unspec., no position 13 Jul. 20sp, 350 humpback	20sp, 400wh	14
Schooner <i>S.R. Soper</i>	1861	Provincetown	At least Feb. 1863	At São Nicolau 9 Feb. no report, no date and no position 25-30wh, CVI no date 60wh	75sp	2
Bark <i>Willis</i>	1861	Mattapoissett	At least 4 Feb.-Apr. 1862	At São Vicente 4 Feb. with 70sp, 12blackfish, ditto Apr. with 70sp, 180wh	146sp, 176wh	7
Bark <i>Willis</i>	1862	Mattapoissett	At least Mar. 1864	At Sal 11 Mar. 1864 310 unspec., Barbados 12 May shipped 195wh (of which 55 was from a humpback taken in Barbados)	50sp, 700bone, sent home 303sp, 195wh	Poss. 6 (1864)
Bark <i>R.L. Barstow</i>	1862	Nantucket	At least 3 Mar.-12 Jun. 1863; at least Feb 1864; at least 3 May 1865	At Boa Vista 3 Mar. 1863 with 80sp, at ditto 8 Apr. with 100sp, no date with 25-30wh, at CVI no date with 80sp, at ditto 12 Jun. with 70sp, 100 'Hump Back'; at Boa Vista before 29 Feb. 1864, off Bissau, W Africa 5 May with 60wh; at Boa Vista 3 May 1865 having gotten 50sp, 200 humpback, 1200bone in last 90 days	360sp, 556wh; [370sp, 450 humpback, 2000bone all told (Wood)]	4 (1863); poss. 2 (1864); 8 (1865)

Table 3 continued.

Rig and Vessel	Year sailed	Home port	Time at CVI	Basis for inference	Published returns	Est. catch
Bark <i>Ariel</i>	1862-63(?)	Mattapoisett	At least 9 Feb.-?	At São Nicolau 9 Feb. 1863, no date and no position with 25-30wh, at CVI no date with 60wh, at St Thomas (São Tomé) 15 May 1864	No information	2
Brig <i>Annawan</i>	1863	New Bedford	At least Sep. 1864 and Feb. 1865	Called at São Tiago 11 Sep. 1864 with only sperm on board, called at CVI 9 Feb. 1865 with 30sp, 30wh	121sp, 45wh, sent home 210sp [returned with 125sp, 45wh (Wood)]	Poss. 1 or 2
Bark <i>Solon</i>	1863	New Bedford	At least Apr. 1864; 18 Apr. 1865	At São Nicolau 12 Apr. 1864 with 100 humpback, Fayal 11 Jul. 350 humpback (Wood IV:191); at CVI 18 Apr. 1865 with 200 humpback (WSL 23(16):20 VI 1865)	117sp, 351wh, 1600bone, sent home 163sp, 300wh	14 (1864); 8 (1865)
Bark <i>Thomas Winslow</i>	1864	New Bedford	?	Visited Cintra Bay Ground Feb. 1865 (at Goree 17 Feb. with 40sp on board - Wood)	23sp, 300wh, 1450bone, sent home 150sp [arrived home after 16mo. with 200sp, 300 'HumpBack oil' (Wood)]	Poss. 12
Schooner <i>S.N. Smith</i>	1864	Boston	At Sal some time before Apr. 1865	Arrived Barbados 13 Apr. 1865 with 75sp, 100wh - possibly from CVI	190sp, 100wh, sent home 84sp [275sp, 100wh, sent home 80sp (Wood)]	4
Schooner <i>William Martin</i>	1865	Boston	At least 25 Feb.-20 Apr. 1866	At São Vicente 25 Feb. 20sp, ditto 20Apr 125sp	203sp, 18wh	1
Schooner <i>S.A. Paine</i>	1867	Provincetown	At least 6 Mar.-25 Apr. 1869	At São Vicente 6 Mar. 60 humpback, ditto 25 Apr. 380 oil all told (WSL)	180sp, 180wh, sent home 114sp	7
Schooner <i>Edith May</i>	1867	Wellfleet	At least 6 Mar. 1869	At São Vicente with 1 whale as of 6 Mar. (WSL 27(9):27 IV 1869)	260sp, 85wh, sent home 85sp	3
Brig <i>D.A. Small</i>	1868	Provincetown	At least 6 Mar. 1869	At São Vicente 6 Mar. boiling a whale (WSL 27(9):27 IV 1869)	206sp, 1wh	1
Schooner <i>Chas. A. Higgins</i>	1868	Provincetown	At least 6 Mar. 1869	At São Vicente with 1 whale as of 6 Mar. (WSL 27(9): 27 IV 1869)	80sp, 200wh, sent home 56sp	8
Schooner <i>Louisa A.</i>	1867	Boston	At least 20 Feb. 1870	At Flores 18 Aug. 1869 clean, Bermuda 22 Nov. 4sp, 40 humpback, sailed from Bermuda 8 Dec., at São Vicente 20 Feb. 1870 with no oil since last report, arrived with 50sp, 200wh.	50sp, 200wh, sent home 271sp	6
Schooner <i>S.A. Paine</i>	1870	Provincetown	Feb.-Mar. 1871?	At São Vicente 1 Feb. bound sperm whaling, to 'return to St Vincent March 1 st , for humpbacks' (WSL 29:1871)	151sp, 229wh	9
Schooner <i>Petrel</i>	1871	New Bedford	At least Mar. 1872	At CVI 23 Mar. 1872 with 100sp, then Bermuda mid-Jun. with 120-130bbl humpback	11sp, 112wh [10sp, 120 humpback (Wood)]	5
Schooner <i>William A. Grozier</i>	1875	Provincetown	At least 20 Feb. 1876	At São Tiago 20 Feb. 30wh (WSL 34(9):18 IV 1876)	680sp, 30wh	1
Schooner <i>Antarctic</i>	1881	Provincetown	At least 19 Jan.-23 Apr. 1882	At CVI on 23 Apr. 28 humpback (WSL 40(6):21 III 1882; 40(17):6 VI 1882)	100sp, 25wh	1
Schooner <i>Alcyone</i>	1884	Provincetown	At least Mar. 1885	At CVI on 22 Mar. with 50 humpback; 12 May 80 humpback, 25 of which trans-shipped in Barbados (WSL)	180sp, 50wh	3

Table 4
Summary of records, by type and island, for all Cape Verde Island locations.

Island	Total records	Record type	
		Whales	No whales
Boa Vista	59	55	4
Brava	10	10	
Maio	2	2	
Sal	105	98	7
Santa Luzia	33	29	4
Santo Antão	39	24	15
São Nicolau	109	99	10
São Vicente	95	79	16
Total	452	396	56

Records of humpback whales

The numbers of records ('whale' and 'no whale') are summarised by month in Table 5. Approximately 90% of the whale records were in February, March and April. As noted in Reeves *et al.* (2001), it was difficult to interpret the 'no whale' records. The absence of whales would probably be recorded in the logbook only on days when sighting conditions were acceptable and there was some search effort, although it could not be assumed that the whalers' thresholds of 'acceptable' sighting conditions and the quality of their search effort were in any sense standardised. While it may be reasonable to conclude that whales were not present in the immediate vicinity of the vessel on 'no whale' days, the very fact that the whalers were searching for them implies an expectation of finding humpbacks in the area, and this

Table 5
Summary of Cape Verde Islands whale-related records by month. There were no records for the months of July to November.

Month	Whale records	'No whales' records
January	7	3
February	110	13
March	160	21
April	86	12
May	27	6
June	2	1
December	4	-
Total	396	56

expectation may have arisen from empirical knowledge concerning whale distribution and movements. No further consideration of the 'no whale' records was judged appropriate.

Records of humpback whales are summarised by region in Table 6, together with estimates of the total numbers of whale encounters. These estimates involve assumptions regarding the number of whales represented by terms such as 'few' or 'many' (see above); given this, as well as probable inaccuracies in reporting, the estimates should be treated as no more than crude approximations. It is also important to emphasise that two disparate types of data have been combined for this analysis. 'Taken' whales, and probably at least some 'struck' whales, represent unduplicated removals from the whaling ground, whereas 'seen' whales (and to some extent 'struck' whales) probably include repeat encounters with the same individuals. It is possible that, given the relatively small spatial scales of these concentrated fisheries, same-day and between-day sightings of a whale or whales have inflated the number of sightings; however, there is no way of assessing the existence or extent of this bias in the data. Despite such caveats, we believe that these encounter rate data probably provide reasonably valid indications of the relative abundance, or density, of whales in each of the regions. Of the estimated 1,105 humpback whale encounters, the largest numbers were reported from Sal (estimated total 272, or 24.6%), followed by São Vicente (269 whales, 24.3%), São Nicolau (229 whales, 20.7%) and Boa Vista (150 whales, 13.6%). Of the nine islands, Maio and Brava had the fewest encounters (estimated at 8 and 27, respectively).

The numbers of humpback whale encounters off each island for the December-June period are shown in Fig. 2. Peak numbers appear to have occurred in March, with substantial numbers of records for February and April. Once again, however, it must be stressed that these records were not corrected for effort and thus only crudely reflect the occurrence of humpback whales.

Estimated humpback whale catches and vessel-seasons in the Cape Verdes

The total number of humpback whales secured or known to have been killed but lost between 1815-1901, based solely on the 'read' sample, was 89 (Table 7). In addition, 61

Table 6

Summary of records of humpback whales, for all Cape Verde Islands locations, and estimates of total number of whale encounters represented by these records. Areas for which no whale records were found were omitted. Some whales were reported in the logbooks as an exact number of animals, and these are shown here in the categories *Taken*, *Struck* and *Seen*. In other cases, whalers recorded observations of whales with no number of animals specified, using instead a variety of descriptive terms; these terms are grouped here into the three categories *Few*, *Several* and *Many*. For the purpose of estimating whale numbers, the following values were arbitrarily assigned to these three categories: *few* = 2, *several* = 4, *many* = 10. The resulting estimated numbers are given in the *est whales* column under each of the three categories; the previous column (*Records*) shows the number of records found for each category (in *italics*, since these are not included in the *Total Whales* column at the end). See text for other definitions.

Island	Total whale records	Humpback whale encounters										Total whale encounters
		(Exact) nos of whales recorded				Whale reports with exact nos not specified						
		Taken	Struck	Seen	'Few'		'Several'		'Many'			
					<i>Records</i>	Est. whales	<i>Records</i>	Est. whales	<i>Records</i>	Est. whales		
Boa Vista	55	20	18	12			25	100				150
Brava	10	2	3	2			5	20				27
Maio	2						2	8				8
Sal	98	17	19	40	2	4	43	172	2	20		272
Santa Luzia	29	2	4	12			14	56				74
Santo Antão	24	3	3	2			17	68				76
São Nicolau	99	11	19	75			31	124				229
São Vicente	79	13	12	30			41	164	5	50		269
Total	396	68	78	173	2	4	178	712	7	70		1,105

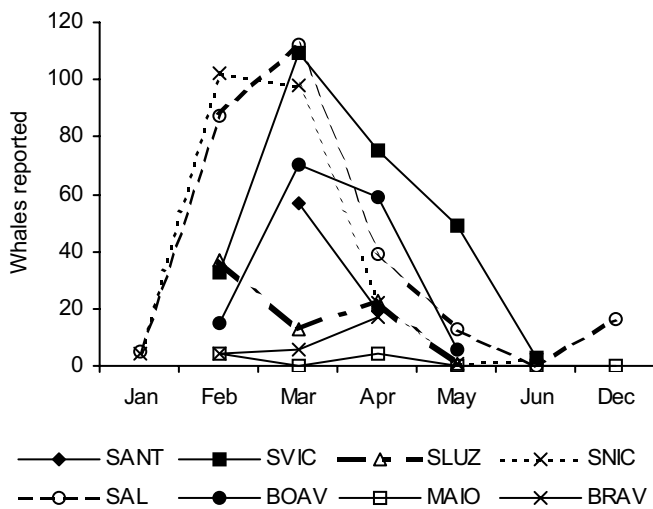


Fig. 2. Estimated numbers of humpback whales observed (sightings, strikes and kills) by month and island. Abbreviations are as follows: SANT Santo Antao, SVIC Sao Vicente, SLUZ Santa Luzia, SNIC Sao Nicolau, SAL Sal, BOAV Boa Vista, MAIO Maio, BRAV Brava.

struck/lost whales were documented. The total estimated catch from the 'sighted vessel' sample was 167-201+ between 1852-1886, and from the 'extrapolation' sample 230-266 between 1853-1884. Estimated removals from 1850-1879, with no adjustment to account for killed/lost or struck/lost whales in the 'sighted vessel' and 'extrapolation' samples, but assuming 100% mortality for all struck whales in the 'read' sample, total 518-581.

The estimated total of vessel-seasons documented from the 'read' sample was 25, the 'sighted vessel' sample 38-40 and the 'extrapolation' sample 37-43, for a grand total of 100-108. Of these, 88-94 took place between 1850-1879.

Peak period of humpback whaling in the Cape Verdes

New England whalers apparently began taking large numbers of humpbacks in the 1830s and effort remained reasonably high for six decades (Mitchell and Reeves, 1983). After about 1888 there seems to have been little interest in humpbacking. The earliest CVI humpback voyage documented in this study was by the brig *Edward* of Nantucket (1815-17 MS) which whaled at Sal from 21

April-4 May 1816 (1 humpback struck). On an 1812 sealing voyage by the brig *Nanina* of New York, the captain and a crew member 'Lanced a Hump back calf whale' at the Cape Verdes on 24 May (Dodge, 1986). This event appears to have been atypical although it serves to demonstrate that humpback whales were at least casually hunted at the CVI by American seamen from as early as the second decade of the 19th century. The brig *By Chance* of Dartmouth (1826-28 MS) cruised mainly in eastern Atlantic equatorial waters for sperm whales and blackfish but also took a humpback calf while anchored at São Vicente in mid-April 1827 (the cow was struck but lost).

Judging by vessel itineraries and oil returns (Wood, no date, MS; Tables 2 and 3) it appears that considerable effort was devoted to humpback whaling in the CVI during the 1850s (also see Table 7). Two 'read' voyages, those by the Provincetown schooner *E. Nickerson* (1853-54 MS) and the Nantucket brig *Homer* (1855-56 MS), included seasons of CVI humpbacking. The *Homer* logbook reported at least four other vessels humpbacking on the same grounds in early 1856: the Nantucket schooners *William P. Dolliver*, *Watchman* and *Hamilton*; and one of the three New Bedford barks named *Osceola* (see Starbuck, 1878, pp.516-7). The master of the *Watchman* drowned at Boa Vista on 31 May 1856, and the vessel returned to Nantucket with 530bbl of whale oil after a cruise of only 6½ months (Starbuck, 1878, pp.530-1).

The logbooks examined in this study confirm that whaling pressure on humpbacks had become particularly intense at the CVI by the mid-1860s (Table 7), a trend mirrored by that in the West Indies (Mitchell and Reeves, 1983). One whaler noted in his journal during a brief visit to Boa Vista in late January 1866, 'humpbacking, for which these Islands are very well noted among all whalers ...' (S.R. Soper, 1865-66, MS). The logbooks of the *Stafford* (1865-67, MS), *Walter Irving* (1865-66, MS), *Petrel* (1865-66, MS), *Solon* (1865-66, MS) and *Osceola 3rd* (1865-66, MS a; MS b) indicate that at least 28 American whaling vessels were present in the CVI during the winter whaling season of 1866, and at least 16 of these were humpbacking. Itineraries and returns from Starbuck (1878) and Wood (no date, MS) strongly suggest that at least four of the others (*Varnum H. Hill*, *Willis*, *Sassacus* and *Rising Sun*) took humpbacks in the CVI, and the brig *Julia* of Fayal (Azores), which arrived at

Table 7

Known and estimated catches of humpback whales and whaling effort (defined as total vessel-seasons, counting only those in Tables 1-3 where some attempt to take humpbacks, however desultory, was documented or inferred) in the Cape Verde Islands by decade and sample.

Sample	1815-49	1850-59	1860-69	1870-79	1880-89	1890+	Total
<i>Read</i>							
Whales secured/killed ¹	1	27	30	24	6	1	89
Whales struck and lost	2	18	22	10	9	0	61
Vessel-seasons	2	4	10	4	3	2	25
<i>Sighted Vessel</i>							
Whales taken ²	0	41-43	108-133	12	6-13+	0	167-201+
Vessel-seasons	0	10	22	3	2-4	1	38-40
<i>Extrapolation</i>							
Whales taken ³	0	73-87	132-154	21	4	0	230-266
Vessel-seasons	0	13-15	18-22	4	2	0	37-43
<i>Totals</i>							
Whales (killed and struck combined)	3	159-175	292-339	67	25-32+	1	547-617+
Vessel-seasons	2	27-29	50-54	11	7-9	3	100-108

¹ Includes whales killed, secured and processed; whales killed but not secured (e.g. sank); and calves that were struck themselves or whose mothers were struck or killed.

² Includes only whales secured and processed, or described as having been killed and lost. In some instances the secured total was estimated from oil returns assuming 25bbl/whale.

³ Includes only whales secured and processed, mainly estimated from oil returns assuming 25bbl/whale.

Sal on 11 February 1866 (*Osceola 3d*, 1865-66, MS a), lowered for a humpback near São Nicolau on 16 February while 'Cruising for Sperm Whales' (*Julia*, 1865-66, MS). Thus, effort amounted to at least 21 vessel-seasons in 1866. The *Petrel* (1865-66, MS) journal was particularly revealing, referring to at least nine of the other humpbacking vessels and recording no less than 13-14 humpbacks taken, 2-3 killed but lost and 14 struck but lost. This vessel's humpbacking season spanned the entire period from 3 February, when it was in the lee of Boa Vista and 'waiting for the humpbacks to come along', to 27 May, by which time most of the other humpbacking vessels had departed the region. Four of the vessel captains had agreed on 5 March to stop chasing humpbacks for three days 'so as to give them a chance to come inshore'. Humpback baleen was being processed and stowed, as evidenced by the fact that on 5 April the *Petrel's* crew boarded the *Winslow* 'and got our bone' (from a 40bbl cow humpback taken on 3 April). Later the same day they 'cleaned' the bone. The *Winslow's* crew came on board the *Petrel* on 11 April 'to show our officers how to cut in the Humpback. They were never Humpbacking before'. At least some of the vessels were using bomb lances to kill the whales (*Petrel*, 1865-66, MS; *Walter Irving*, 1865-66, MS).

A 'large fleet' of Provincetown vessels was again in port at São Vicente in March 1867 (Report from the schooner *William Martin* of Boston in WSL, 19 March 1867). As of then, only a few humpbacks had been taken. 'There had been a few humpbacks about the Islands, but they were shy, and with so many vessels after them, the chance is very small to take humpback oil this season' (*Ibid.*; also see Wood, no date, MS; Table 3). The schooner *William A. Grozier* of Provincetown (1866-67, MS), having spent the first winter of the same voyage (February-April 1866) humpbacking in Tobago, West Indies, was humpbacking around São Nicolau, Sal and São Vicente for most of March 1867. In late February or early March 1867, the *Grozier* observed the *William Martin*, the Provincetown schooners *Sassacus* and *Montezuma*, the Wellfleet schooner *Edith May* and the New Bedford ship *Commodore Morris* - also on the CVI humpbacking grounds. The Fairhaven schooner *Washington Freeman* (1868-70, MS) spent the period from mid-February to early April 1869 humpbacking around Brava and Fogo islands but secured only two whales. No other vessels were reported to be present in this area but the Provincetown schooner *Albert Clarence* (1868-70, MS) and several other vessels (*Edith May*, a Wellfleet schooner; *A.R. Tucker*, a New Bedford bark; *Abbie H. Brown* and *S.A. Paine*, both Provincetown schooners; all reported in the *Clarence* log) were present and apparently humpbacking in the northwestern portion of the archipelago. The Edgartown bark *Perry* took several humpbacks at the CVI in 1876, as did the Provincetown schooners *Clara L. Sparks* in 1877 and *Express* in 1878 (see Table 1). The schooners *Golden City* of New Bedford, *Crown Point* of Provincetown and *Admiral Blake* of Marion humpbacked at the CVI in 1883 (*Ibid.*). In contrast, the New Bedford schooner *Eleanor B. Conwell* (1880-82, MS) called at the CVI in the last week of January 1881 but only chased blackfish before heading southwards and westwards for sperm whales.

All indications are that by the mid-1880s, both effort and catch in the CVI were much less than they had been in the 1860s. The latest CVI humpback voyage in the 'read' sample was by the schooner *Adelia Chase* of New Bedford (1901-02, MS) which spent about two weeks (27 February-12 May) humpbacking at Sal and Boa Vista in 1902 (one 'bull' taken off Coral Point, Madeira Bay, on 5

March). Based on the logbooks of other winter voyages to the CVI in the late 1880s, 1890s and early 1900s (e.g. *George and Mary*, 1888-91, MS, 1892-94, MS) it is concluded that humpbacking had become desultory and that the focus was on sperm whaling, blackfishing, recruiting and provisioning. It is tempting to conclude that few humpbacks were available around the CVI by this time, but the influence of market factors (e.g. the declining price of whale oil, the increasing value of sperm oil and balaenid baleen; Tower, 1907; Bockstoce, 1986) cannot be discounted in trying to explain the reduction in effort and catch. Again, the trend mirrored that in the West Indies (Mitchell and Reeves, 1983).

Seasonality

Humpbacking at the CVI was primarily a winter and spring activity although one contemporary observer (E.J.M., 1864) described the season as extending from January to July, i.e. from mid-winter to mid-summer. Most of the evidence in whaling manuscripts suggests that humpbacks did not arrive until at least mid-January. For example, the brig *Homer* of Nantucket (1855-56, MS) arrived at Sal on 11 January 1856 with the clear intention of humpbacking. The logbook entry for 17 January states, 'no humpbacks on the ground yet'. The entry for 22 January states, 'waiting patiently for humpbacks to come in'. The first humpback of the season was sighted at Sal on 3 February. The *E. Nickerson* (1853-54, MS) chased the first humpbacks of the 1854 season at Sal on 1 February. After an initial four-day run of whales, the master complained in his journal on 10 February, 'Oh where is the hump Backs'. More whales, including two cow-calf pairs, were sighted and chased on 13 February. In 1866 the *Walter Irving* (1865-66, MS) came to anchor in Madeira Bay, Sal, on 13 January and was soon joined by several other American whalers. No humpbacks had arrived yet and none were seen until 16 February. The Provincetown schooner *Clara L. Sparks* (1876-77, MS) first encountered humpbacks on 30 January 1877 while approaching Sal from the north. Thereafter the *Sparks* visited Boa Vista and São Tiago and engaged in blackfishing before commencing the humpback season at Sal on 12 February. The *Petrel* (1865-66, MS) arrived at Boa Vista on 3 February 1866 - 'All we are now waiting for is the humpbacks to come along'. The first sightings there were made on 6 February.

Humpbacks appear to have departed the islands in most years by no later than the second week of June. The *Stafford* and *Para* were still cruising for whales off São Vicente and in Calm and Pedro bays in the first few days of June 1866 (*Stafford* 1865-67, MS). The latest catch reported in the *Stafford* logbook was the cow-calf pair taken by the *Quickstep* on 25 May but humpbacks were seen and chased off São Nicolau as late as 2 June. The *Stafford* logbook entry for 8 June (at São Vicente) states: 'Whales [humpbacks] have about all left for the season' (*Stafford*, 1865-67, MS). In 1854 the master of the *E. Nickerson* (1853-54, MS) wrote in his journal that the humpbacks seen in Madeira Bay (Sal) on 11 May were 'small and wild' and that 'they must be the last that will pass this season'. Nevertheless, the *Nickerson* took a cow-calf pair at Boa Vista on 13 May and struck but lost a humpback there on 17 May.

Composition of the CVI humpback population

Cow-calf pairs were regular targets of the whalers in the CVI. Standard practice was to harpoon but not kill the calf so that the mother would 'stand by' and be more easily harpooned (this was typical of the pelagic whalers; see Tilton, 1969, pp.75-6). Usually the logbook entries are

ambiguous concerning the fates of calves. Even when it is clear that a calf was struck, there may be no further indication as to whether it was secured or cut loose. In assessing removals, the most reasonable assumption is that when a cow was taken, the calf would die regardless of whether it was struck (see Mitchell and Reeves, 1983).

There was also some suggestion that cows and calves appeared on the grounds well after the first humpbacks had arrived. For example, the *Stafford* was on the grounds, cruising mainly in the channels between São Vicente and São Nicolau, from 20 January 1866 but did not see any cow-calf pairs until 26 March (*Stafford*, 1865-67, MS). It is uncertain whether cows arrived pregnant and gave birth near the CVI or instead arrived after having given birth elsewhere. A cow-calf pair was reported on 28 December 1888 at 20°42'N, 20°38'W, in deep water (>3,500m) about 500km northeast of Sal (*Eunice H. Adams*, 1887-90, MS). Assuming that they were headed for the CVI, this would indicate that at least some of the mothers arrived post-partum.

The take at the CVI was said by E.J.M. (1864) to have consisted of more cows than bulls, but this claim was impossible to evaluate from the logbooks. Keepers recorded information on the sex of whales in a non-systematic fashion, with a likely bias toward reporting cow-calf pairs.

Comparison with the West Indies

Table 8 gives mean values for humpback whale encounter rates for the Cape Verde Islands and the three selected West Indies whaling grounds. The area with the highest mean encounter rate was Trinidad/Gulf of Paria/Venezuela (1.47 whales per day overall), although this was based upon data from only six voyages. The lowest encounter rate was from the Dominican Republic and Puerto Rico (0.64 whales per day overall). Despite the fact that the 'principal' West Indies whaling ground from Guadeloupe to the Grenadines had the highest numbers of both vessels employed and whale records, the mean encounter rate there (0.8 whales per day) was somewhat lower than for the CVI (0.96 whales per day). Due to the biased nature of these data (see earlier), no attempt has been made to compare them statistically and they should be viewed as providing only a rough guide to the comparative density of whales in each location.

Other species

Most of the American whalers who hunted humpback whales at the CVI appear to have been 'combination whalers', i.e. they took sperm and pilot whales as well as baleen whales on at least a seasonal or opportunistic basis. Sperm oil was stored separately from 'whale' oil, the latter often including a mix of oils from humpback whales, right

whales and the occasional *Balaenoptera* sp. that might have been taken opportunistically. Although as Best (1987) noted, the oil from pilot whales (blackfish) was 'rated as common whale oil' (see Clark, 1887a), it was not consistently included in the reported whale oil returns; nor was that of the killer whales, 'grampuses', 'cowfish' and 'porpoises' taken from time to time.

While searching for humpback whales near the CVI, the whalers occasionally interrupted their activities to chase blackfish or sperm whales. For example, the *Golden City* mated with the *Admiral Blake* on 3 February 1883 while the two vessels were humpbacking off São Nicolau, with an arrangement that there would be equal shares 'for everything caught except Blackfish' (*Golden City*, 1882-84, MS). On the next day the *Golden City* boats were lowered twice for humpbacks and once for blackfish. After finishing trying out a humpback on the 15th, the *Golden City* crew chased a school of sperm whales on the 16th. On the 22nd they chased blackfish early in the day, then joined the *Admiral Blake* crew to chase sperm whales (2 were struck and lost) in the afternoon. For the next two weeks all attention (both ships) was devoted to humpbacks. In the second week of March they relocated to Santo Antão, where they alternately chased humpbacks and blackfish.

'Finbacks' were sometimes observed on the CVI humpbacking grounds and the whalers occasionally killed them with bomb lances (e.g. *Walter Irving* in company with *Antarctic*, 27 January 1866 in Madeira Bay, Sal; *Leonidas* and *Solon*, 14 February 1866 at São Nicolau). The crew of the bark *Osceola 3rd* (1865-66, MS a) prepared to lower for what they thought was a humpback but proved to be a 'sulphurbottom' (blue whale) at 21°28'N, 20°48'W (ca 575km north-northeast of Sal) on 29 January 1866.

Four references were found to killer whales at the CVI. Some were seen at the same time as humpbacks in the channel between Santa Luzia and São Vicente (6 March 1866; *Stafford*, 1865-67, MS); one was killed at Santo Antão (2 January 1868; *Star Castle*, 1867-68, MS); and some were seen at 18°18'N, 21°48'W (17 January 1891; *George and Mary*, 1888-91, MS) and at 19°01'N, 19°41'W (18 April 1816; *Edward*, 1815-17, MS).

Shore whaling at the CVI

In the West Indies, vessels generally hunted for humpback whales by cruising daily in the bays or inter-island passages and anchoring at night. In contrast, in the CVI the vessels often remained at anchor inshore while the boats deployed from there. This means that what was essentially 'bay whaling' by pelagic whalers (cf. Bannister, 1986; Dawbin, 1986) could be misconstrued for shore-station whaling.

Table 8

Comparison among whaling grounds of humpback whale encounter rates by time spent on the ground. Voyages spending fewer than ten days on the ground in question were ignored. For each area, the total number of days spent on the ground by each voyage ('vessel days') was divided into the total number of takes and strikes and the total number of whale sightings recorded by that vessel; values given are means and standard deviations for all voyages to that ground. The final columns ('Total whales per day') give the observed values for all whale records (i.e. takes, strikes and sightings combined).

Whaling ground	Voyages	Total vessel-days on ground	Takes/strikes per day		Sightings per day		Total whales per day	
			Mean	SD	Mean	SD	Mean	SD
Cape Verde Islands: all areas	14	994	0.13	0.1	0.82	0.45	0.96	0.44
West Indies: Trinidad, Gulf of Paria, Venezuela	6	324	0.19	0.18	1.29	0.59	1.47	0.72
West Indies: Guadeloupe, Dominica, St Vincent and the Grenadines, Barbados	32	2,277	0.11	0.1	0.69	0.59	0.8	0.62
West Indies: Dominican Republic, Puerto Rico	5	235	0.1	0	0.59	0.23	0.64	0.24

Clarke (1954) found no evidence of a shore-based whaling industry in the CVI but Hazevoet and Wenzel (2000) cited several 19th century sources indicating that whaling companies were established on São Nicolau in 1874 and on Sal in 1883. They gave no details about these operations. Also according to Hazevoet and Wenzel (2000), whaling stations on São Nicolau and Maio still existed in 1912 but had by that time 'all but ceased due to the scarcity of whales'. In the present study, only a few cryptic references were found to shore whaling and there was little suggestion of the close interaction between local people and American whalers that characterised winter humpbacking in some other areas (e.g. Adams, 1971; Aguilar, 1985).

In March 1854, a humpback was struck near Sal by a shore-based crew (Mr Fisher and co.). Having lost their lances, the men asked to borrow some from the schooner *E. Nickerson* (1853-54, MS). Instead of loaning them the lances, the *Nickerson's* captain dispatched one of his own boats to take the whale, then gave half the carcass to the shore party. On 5 March 1866, while the *Thomas Winslow*, *Antarctic* and *Walter Irving* were humpbacking at Sal, there were 'also quite a number of shore boats about here' (*Walter Irving*, 1865-66, MS). These records indicate that some shore whaling took place at Sal prior to 1883. Also in March 1866 the bark *Osceola 3rd* of New Bedford (1865-66, MS a) was flensing a humpback at Boa Vista and five boats 'came off from shore to help'. In early April 1876 the bark *Perry* of Edgartown (1874-77, MS) 'mated' with a shore party 'here Engaged in Humpbacking, in Equal Shares'.

On 17 February 1886, the brig *Eunice H. Adams* (1885-87, MS) of Edgartown was cruising for humpbacks off Tarrafal Bay (São Nicolau) when a waif (a makeshift flag) was sighted in the bay. A boat, apparently based on shore, had gotten fast to a humpback and was signalling for assistance. A boat from the *Adams* proceeded to secure the whale and tow it alongside the schooner *Chas. W. Morse* of New Bedford for flensing. Although reference was made in the *Adams* logbook to sharing the oil with the *Morse*, there was no mention of allocating a share to the shore-based crew. Later in the same cruise (20 March) the logbook records:

'...the shore party struck a whale Signaled for help and the waist boat went to them their line shot one bomb into the whale, and then found that they had no more cartridges in the boat. The iron parted and so ends a miserable days work'.

This record corroborates the report by Hazevoet and Wenzel (2000) that shore whaling was underway at São Nicolau in the 1880s.

In an unspecified year prior to 1864, a European resident of one of the islands observed the taking of a humpback in a local harbour (E.J.M., 1864). This whale had originally been harpooned and lost by an American whaling crew near another island some 60 miles distant, and it was attacked by miscellaneous makeshift crews in boats launched from shore and from merchant vessels in the harbour. A boat from an American whaling ship finally arrived on the scene, killed the whale and towed it to the ship for processing (22bbl, or 1,100gal of oil).

DISCUSSION

Abundance, movements and stock identity

The data presented here indicate that the Cape Verde Islands was a major winter destination for humpback whales in the 19th century. The crude encounter rate figures calculated above suggest that whale density in the CVI was at least as high as in the West Indies, including in the 'principal'

whaling ground from Guadeloupe to St Vincent and the Grenadines. Although humpbacks are still found in the CVI today (Reiner *et al.*, 1996; Hazevoet and Wenzel, 2000; Jann and Wenzel, 2001), the local density is much lower than that found in the major West Indies breeding grounds north of the island of Hispaniola (see Winn *et al.*, 1975).

Based on little evidence (song-pattern similarity), the whales that migrate to the CVI and West Indies were considered to belong to a common stock (Winn *et al.*, 1981). This hypothesis appears to be inconsistent with the fact that the two North Atlantic wintering areas were (and still are) occupied simultaneously by parturient females and singing males, and that there is little historical evidence to suggest regular movement by humpback whales across the North Atlantic Ocean in low latitudes. Although the American whalers reported occasional sightings west of the CVI (e.g. 18°48'N, 26°20'W on 9 March 1867 – *E.H. Hatfield*, 1867-68, MS; 15°20'N, 28°50'W on 21 March 1890 and 16°30'N, 26°30'-27°W in late March 1891 – *George and Mary*, 1888-91, MS), such encounters were exceptional as the whalers traversed the Atlantic from east to west with the trade winds. Acoustic data nevertheless suggest that considerable numbers of humpback whales spend time in mid-ocean waters of the North Atlantic (C. Clark, pers. comm.).

A more plausible hypothesis, in our judgement, is that the humpback whales wintering in the CVI are part of an eastern North Atlantic population that undertakes a north-south migration in European waters. Several sightings recorded in the whaling logbooks are suggestive of migration routes. A humpback was seen near the island of Madeira (ca 32-33°N, 18°W) on 2 January 1868 (*Ansel Gibbs*, 1867-68, MS) and the next year on 19 December the same vessel lowered its boats to chase a humpback 16km west of Madeira (*Ansel Gibbs*, 1869-70, MS). In addition to the cow-calf pair reported by the *Eunice H. Adams* at the end of December 1888 about 500km northeast of Sal (see above), humpback whales were observed earlier in the same cruise 'going quick' at ca 25°N, 26°W on 10-11 February and 'going quick towards St Antoine [Santo Antão]' at 18°N, 25°45'W on 26 February (*Eunice H. Adams*, 1887-90, MS). In these latter instances the whales were in deep water (> 3,000m) of the south-flowing Canary Current. Several other sightings were made in early to mid-December 1850 in deep water directly east and northeast of Sal (16°45'-17°30'N, 20-22°W) (*Medford*, 1850-51, MS).

The humpbacks taken off northern Norway in the late 19th and early 20th centuries seem not to fit the model of a north-south feeding-breeding migration to and from the CVI, or for that matter to and from the West Indies (Christensen *et al.*, 1992). They remained in northern waters from August until late in the winter, then migrated west along the Finnmark coast in February-April, at which time the adult females were pregnant with large fetuses (Ingebrigtsen, 1929). With regard to the breeding area of this population, Ingebrigtsen speculated that it could have been just south of Ireland, noting that Norwegian whalers working from Cape Finisterre and Gibraltar had not reported seeing humpbacks. Christensen (1980; citing Benjaminsen *et al.*, 1976 and Jonsgård, 1977) concluded that the northeastern Atlantic population of about 1,200-1,500 humpbacks was reduced to very small numbers by modern whaling from 1881-1910.

Slijper *et al.* (1964) plotted a few sightings in the eastern Atlantic between 10°N-10°S during the boreal winter (November-March) and concluded that they were Northern Hemisphere animals because this was outside the whaling season at Gabon (June-October). Townsend's (1935) chart

shows only one offshore record between the Equator and 10°N in the eastern Atlantic and the month is August (austral winter). His plots overall suggest a hiatus between the equatorial concentration off Gabon and the CVI. Moreover, all of his plots for the Gulf of Guinea are for June-September while those for the CVI are for February-May, which is consistent with the logbook data in this paper. There was nothing in the logbooks examined for the present paper (or indeed in those examined by Reeves in other previous and subsequent studies) to suggest that any humpback whaling took place in the CVI outside the period January to early June.

It is possible that animals from the North Atlantic occasionally move south from the CVI and into equatorial waters during the boreal winter and spring (e.g. see Mackintosh, 1965, p.45). However, the historical records examined for the present study (and further logbook studies by Reeves following completion of the work for this paper) revealed no evidence that the whalers expected to encounter humpbacks as they sailed south from the Cape Verdes, at least not until they reached the humpback whaling grounds in the Gulf of Guinea and southwards along the African coast. One instance was found in which humpbacks were sighted on 20 May 1841 at 10°33'N, 22°44'W, approximately 500km south of Maio (*Braganza*, 1840-43, MS). If these were Northern Hemisphere whales, one would have expected them to be north rather than south of the CVI this late in the season. Nevertheless, they were still several times farther away from the Gulf of Guinea than from the CVI, and this would have been rather early in the year for migrants from the Antarctic to have reached, and indeed moved north from, their West African wintering grounds. Nevertheless, Budker and Roux (1968) reported that humpbacks arrived off Gabon about 15 May and departed at the beginning of October.

The reason for the relatively low abundance of humpback whales at the CVI today remains unclear. The area appears to have been a major breeding ground for humpback whales in the 19th century, but overexploitation both in the CVI and in the whales' high-latitude feeding grounds off Europe had severely depleted the population by the middle of the 20th century (Brown, 1976; Christensen *et al.*, 1992). Today, many of the humpback whales off Norway are known to migrate to the West Indies (Stevick *et al.*, 1999); it is possible that a second, smaller group of humpbacks that feeds in the northeastern Atlantic uses breeding grounds elsewhere, e.g. the CVI, and that this group has yet to recover appreciably. If so, humpback whales should be observed with increasing frequency in the CVI in the future as the population increases.

Humpback whale catches at the CVI

The estimated totals in Table 7 are probably negatively biased even though some of the figures for individual voyages may be too high. The 'read' sample represents only a small fraction of the logbooks and journals available in public collections (see Sherman *et al.*, 1986; Lund, 2001) and the extant cumulative collection of logbooks available for examination covers only about 28% of the total voyages by American whalers (Smith and Reeves, 2002). Although the examined sample of logbooks was selected according to expectations of finding CVI humpback data, some documents in public holdings that contain relevant data certainly would have been missed. At least a few voyages bound (or putatively bound) for areas other than the North Atlantic according to Starbuck (1878) or Hegarty (1959) involved the taking of one or more humpbacks at the CVI

(e.g. *By Chance*, 1826; *Parana*, 1856). Therefore the selection against reading the logbooks of such voyages would mean that their catch records were under-represented in the present compilation.

With respect to non-American (e.g. British or French) whaling in the region, there were some instances in which the presence of non-American vessels was recorded in the logbooks (e.g. an English steamer *John Fenwick*, seen at Santa Luzia or São Nicolau on 7 February 1866; *Stafford*, 1865-67, MS) but there was no suggestion, even in the more detailed and legible logbooks, that British or French whalers engaged in whaling for humpbacks in this area. The British whaling fleet was at its peak in 1815 and by 1850 only 23 British vessels were engaged in the southern whale fishery (as opposed to the Arctic fishery for bowhead whales, *Balaena mysticetus*), 'cruising chiefly on the Brazil Bank' (Clark, 1887b). French vessels were prominently involved in the South Atlantic fishery for right whales through the 1830s, after which they cruised mainly in the Pacific (Du Pasquier, 1986). The brig *Julia* (1865-66, MS), which had reportedly sailed from Fayal in the Azores, was the only vessel from a non-American port that was identified in the studied logbook sample as having attempted to take humpback whales at the CVI (Table 1).

Cintra Bay Connection

The schooner *Watchman* of Nantucket was among the most persistent visitors to both the Cintra Bay right whale ground and the CVI humpback ground. There is definite evidence that this schooner whaled for right whales at Cintra Bay in the winters 1856-57, 1857-58, 1859-60 and 1860-61 (Reeves and Mitchell, 1986; Wood, no date, MS). It is also reasonably certain, based on itinerary considerations and returns reported in Wood (no date, MS), that the *Watchman* humpbacked at the CVI in 1856, 1857, 1858, 1860 and 1861 (see Tables 2 and 3). In 1858-59 the *Watchman* obtained 564bbl of whale oil in a nine-month cruise, and according to Wood (no date, MS) was at Boa Vista on 5 April 1859. Probable Cintra Bay voyages not listed in Reeves and Mitchell (1986: their table 4) include: the schooners *Alexander* of Provincetown which apparently took 2-3 right whales (150bbl whale oil; 1,600lb baleen) in February (and possibly January or March) (Wood, no date, MS), *Mountain Spring* of Provincetown which capsized in Cintra Bay in January 1856 (Wood, no date, MS; Starbuck, 1878, pp.530-1) apparently before killing any whales, and *Watchman* of Nantucket which was in Cintra Bay in January 1861 (Wood, no date, MS) and may have taken one or more right whales.

The most intensive whaling effort on the Cintra Bay Ground appears to have lasted for about three seasons: 1855-56 (at least 14 vessels); 1856-57 (at least 13 vessels); and 1857-58 (at least 11 vessels) (Reeves and Mitchell, 1986; new data in the present paper, see above). Thereafter, effort declined precipitously, judging by the itineraries and returns given in Wood (no date, MS), logbooks and other sources (Reeves and Mitchell, 1986; supplemented by data in the present paper). Evidence has been found of only one Cintra Bay voyage in 1859-60, one in 1860-61, one in 1864-65, a very brief one in 1865-66, one in 1875-76, two in 1877-78 and two in 1879-80. The schooner *Sarah E. Lewis* of Boston visited Goree Bay (within the Cintra Bay Ground) on 21 November 1865 but apparently did not stay for long (Wood no date, MS). Similarly, the bark *Solon* of New Bedford (1865-66, MS) simply anchored at the mouth of Cintra Bay on 6 January 1866 and lowered two boats to search for whales in the bay and 'inquire of the Arabs if they

had seen any'. Having sighted no whales and having found no one present at the shore camp, the *Solon* sailed westwards and southwards, eventually spending the balance of the winter humpbacking in the CVI². The rapid depletion of right whales in Cintra Bay during the 1850s probably contributed to the intensification of humpbacking at the CVI in the following decade. In other words, some vessels that otherwise would have spent some or all of the winter in Cintra Bay hunting right whales began going directly to the CVI for humpbacks instead.

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² Entry 21 in Reeves and Mitchell (1986: their table 4) concerning the bark *Silver Cloud* of New Bedford is erroneous. Two vessels named *Silver Cloud* were in the New England fleet at the time, the other being a schooner from New London. The latter was at the CVI in May 1857 with 150bbl of whale oil on board (Wood no date, MS) and it was clearly this vessel, the New London schooner, that was seen and reported at Cintra Bay on 27 December 1856 by the *E. Nickerson* and on 28 December 1856 by the *Walter Irving* (see Reeves and Mitchell, *op cit.*). The schooner *Silver Cloud* appears to have visited the Cintra Bay Ground for two seasons during its 1856-58 cruise.

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- KEY: KWM = Kendall Whaling Museum, Sharon, MA, USA; PPL = Providence Public Library, Providence, RI, USA; NBFPL = New Bedford Free Public Library, New Bedford, MA, USA; ODHS = Old Dartmouth Historical Society, New Bedford, MA, USA; PFM = Peter Foulger Museum, Nantucket, MA, USA; DCHS = Dukes County Historical Society, Edgartown, MA, USA; MHS = Mattapoisett Historical Society, Mattapoisett, MA, USA.
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Movements of humpback whales in Oceania, South Pacific

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ABSTRACT

To investigate movements of humpback whales among breeding and migratory areas of Oceania in the South Pacific Ocean, comparisons of individually identified whales were undertaken using catalogues from New Caledonia, Tonga, New Zealand, the Cook Islands and French Polynesia. These locations probably represent wintering grounds or migratory areas for the Group V and VI stocks, as recognised by the International Whaling Commission for management purposes. Comparisons were also made to small samples of photos from Colombia, Ecuador and the Antarctic Peninsula, representing wintering and feeding grounds of the Group I stock. Overall, the combined catalogues contained photographs of 912 individual whales, 767 of which were from Oceania. Twelve fluke matches were made, indicating movement between the following areas: New Caledonia and New Zealand (2); New Caledonia and Tonga (6, plus one made by dorsal fin); Tonga and the Cook Islands (2); the Cook Islands and French Polynesia (1, plus one made by dorsal fin); and between Ecuador and the Antarctic Peninsula (1). These results add to previously known connections between eastern Australia and the westerly component of Oceania (New Caledonia, Tonga and New Zealand). The data also suggest little movement between Oceania and Area I (western South America and the Antarctic Peninsula), although sample sizes for the latter region were too small to conclude this with certainty. The documented movement of some whales among portions of Oceania indicates that stock assessments based on combining regional estimates of abundance are likely to be positively biased, although this may be countered by problems of heterogeneity in sampling effort and whale distribution. In contrast with the recovery exhibited in Area IV and in the western portion of Area V, humpback whale abundance appears to remain low in Oceania, presumably because of overexploitation in the feeding grounds of Area VI and the easterly component of Area V.

KEYWORDS: HUMPBACK WHALE, SOUTH PACIFIC, OCEANIA, NEW ZEALAND, MIGRATION, BREEDING GROUNDS, POPULATION STRUCTURE

INTRODUCTION

Humpback whales (*Megaptera novaeangliae*) in the Southern Hemisphere are traditionally considered to form five or six distinct stocks or 'groups', which remain isolated year-round (Mackintosh, 1942; 1965; Chittleborough, 1965). During the summer feeding season, these Groups are distributed more or less discontinuously into six Antarctic Areas historically recognised by the International Whaling Commission (IWC) for the purposes of management (Donovan, 1991). Each winter whales from these feeding areas are thought to migrate to discrete breeding and calving grounds in tropical and near-tropical latitudes along continental and insular coastlines. Evidence for these population divisions came initially from the discontinuous, seasonal distributions of humpback catches and migratory movement by Discovery-marked individuals during periods of commercial whaling. More recently, the distribution of mitochondrial (mt) DNA diversity and movement by naturally marked individuals have been used to confirm and refine these divisions (Stone *et al.*, 1990; Baker *et al.*, 1994; 1998; IWC, 1999; 2000b; 2001; Garrigue *et al.*, 2000).

Referred to here as Oceania, the islands of the South Pacific, from New Caledonia in the west to French Polynesia in the east and including New Zealand, lie directly north of

the Antarctic Area V and VI feeding grounds. For this reason, it is generally assumed that humpbacks that winter in Oceania are part of the Group V and VI stocks. Unlike the classic studies of Group IV and V humpbacks by Dawbin (1966) and Chittleborough (1965), however, there is little direct evidence connecting these wintering grounds to Antarctic Areas or to the known migratory corridors along eastern Australia and around New Zealand. Only a handful of Discovery marks placed on the wintering grounds were recovered by Antarctic whaling ships or from shore-based operations in Australia and New Zealand. There is no historical evidence of migratory movement or interchange among the winter grounds of Oceania.

Humpbacks in the Southern Hemisphere were subject to intensive commercial exploitation during the 20th century, with more than 200,000 killed over a seven-decade period (Clapham and Baker, 2001). Almost a quarter of this total represents previously unreported catches by the Soviet Union, which conducted a massive campaign of illegal whaling following the Second World War (Yablokov *et al.*, 1998). Some of the earliest recorded hunting of humpbacks in the Southern Hemisphere was conducted by American whaling vessels near the 'Friendly Isles' of the Kingdom of Tonga and in the vicinity of Chesterfield reef systems, northwest of New Caledonia (Townsend, 1935). While some

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regions of the Southern Hemisphere have shown evidence of strong recovery (e.g. Bannister, 1994; Paterson *et al.*, 1994), the numbers of humpback whales in surveyed regions of Oceania appear to remain low (Abernethy *et al.*, 1992; Gibbs and Childerhouse, 2000; Garrigue *et al.*, 2001).

Since 1991, a number of research projects have been initiated in various parts of Oceania, including New Caledonia, Tonga, the Cook Islands and French Polynesia. These projects have employed photo-id and tissue collection to study the occurrence, distribution, behaviour, abundance, genetics and habitat use of humpbacks at each study site (e.g. Garrigue and Gill, 1994; Baker *et al.*, 1998). This paper reports the results of a comparison of photographic catalogues from these areas, as well as from New Zealand. Photos from Oceania were also compared with more distant study sites off South America and the Antarctic Peninsula to investigate whether the range of Oceania animals extends to the easternmost margins of the Pacific. These comparisons took place as part of two workshops on humpback whales in the South Pacific held at the University of Auckland in March 2000 and April 2001 (Donoghue and Baker, 2000; Anon., 2001). The results provide the first direct evidence of movement among some areas of Oceania and a preliminary assessment of isolation from regions beyond Oceania.

METHODS

Study areas

For the purpose of this paper, Oceania is defined as the large area of islands in the southwestern and south central Pacific Ocean, stretching from New Zealand and New Caledonia in the west to French Polynesia in the east (Fig. 1); geographically, however, Oceania includes a much larger area of island groups in both Southern and Northern Hemispheres. Dedicated surveys for humpback whales in this region were conducted during the austral winter in four

areas: New Caledonia; Tonga; the Cook Islands; and French Polynesia. These areas are described separately below. A small sample of opportunistically collected photographs was also available from New Zealand. It is important to stress that the great majority of islands in Oceania have never been surveyed for the presence of humpback whales, and their use of most of the potentially available habitat is therefore unknown.

New Caledonia

New Caledonia lies between 18° and 23°S and between 158° and 172°E. It consists of one main island and three groups of smaller ones plus many uninhabited atolls, including Chesterfield which was used as a whaling area by the American whaling ships during the 19th century (Townsend, 1935).

Humpback whale surveys were conducted sporadically beginning in 1991 (Garrigue and Gill, 1994), and for three months (July, August and September) each austral winter from 1995 on (Garrigue *et al.*, 2001). The primary study site covers approximately 1,000km² and is located in the southeastern portion of the lagoon off the main island. A total of 277 days of surveys from small boats have been conducted since 1995.

Tonga

The Tongan archipelago is a series of volcanic islands and coral atolls extending from 15° to 23°S and from 173° to 177°W. Tonga consists of three major island groups thought to constitute the primary area of humpback whale density: Tongatapu in the south; the Ha'apai group in the middle; and the Vava'u group in the north. Hunting of humpback whales is known to have occurred in Tonga during the 19th century by American whaling ships (Townsend, 1935) and hunting continued at a low level by local whalers until banned by Royal decree in 1978.

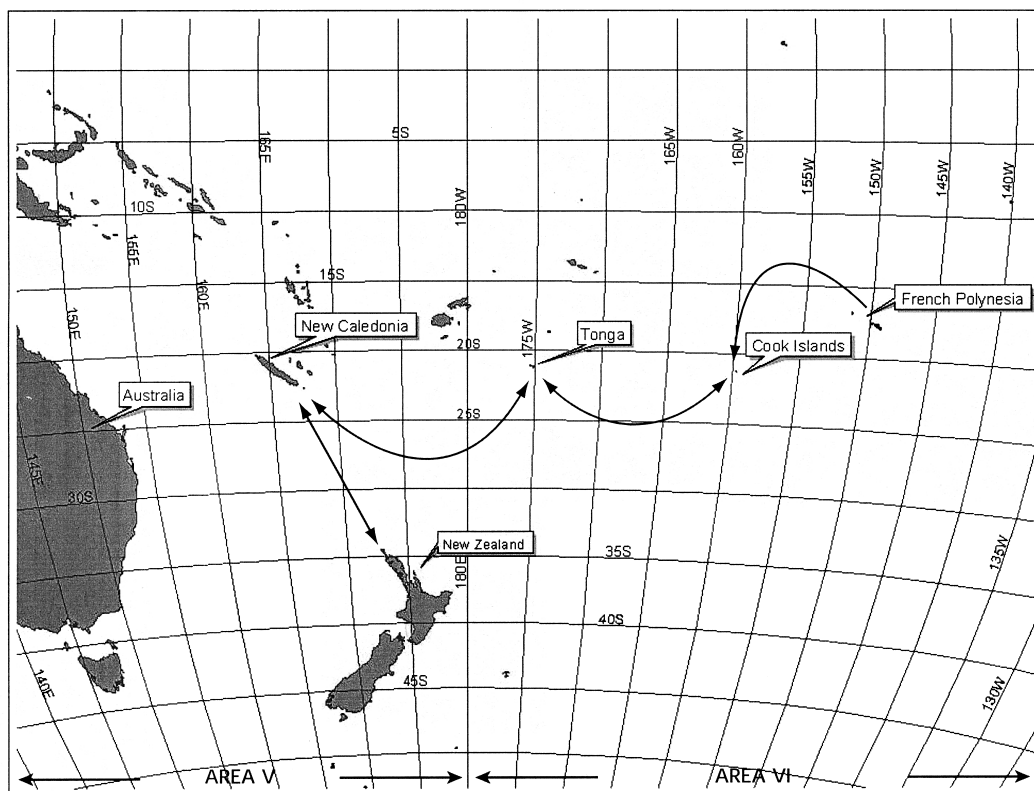


Fig. 1. Map of Oceania, showing the principal study areas.

Vessel-based surveys and the collection of individual identification photographs were initiated in 1991 (Abernethy *et al.*, 1992). Each of the three main island groups has been surveyed in at least one year but most of the field effort from 1994–2000 was concentrated around Vava'u. The majority of fieldwork was conducted in August and early September, although work in some years included late July and early October. The length of the field season varied yearly from approximately 10 days to more than six weeks.

Cook Islands

The Cook Islands extend from 8° to 23°S and from 156° to 167°W, and consists of a few high islands and numerous atolls scattered over approximately 2,000,000km² of the southwestern South Pacific. These islands are divided into two groups, the Northern Cooks and the Southern Cooks; the latter include nine islands and atolls lying between latitudes 18°S and 22°S. Little or no whaling took place in this region in the 20th century and records of earlier (historical) catches there are sparse. Surveys for humpback whales in the Southern Cook Islands began with an exploratory three-week project in 1998 and continued with three-month field efforts in both 1999 and 2000 (Hauser *et al.*, 2000). To date, the survey has been focused on three locations: (1) Palmerston Atoll, a small atoll lying at 18°04'S, 163°10'W on the northwestern margin of the Southern Cook group; (2) Aitutaki, an island located at 18°55'S, 159°47'W, roughly 300km east of Palmerston; and (3) Rarotonga, an island located at 21°14'S, 159°48'W, roughly 430km southeast of Palmerston. A total of 110 days of surveys have been conducted.

French Polynesia

French Polynesia lies between 8° and 27°S and 134° to 155°W in the central South Pacific Ocean. It comprises five groups of islands: the Marquesas; the Tuamotu atolls; the Gambiers; the Society Islands; and the Australs. Sightings of humpback whales throughout French Polynesia's waters have been submitted to a sighting and stranding network since 1988 (Poole, 1993; Poole and Darling, 1999).

The nearshore waters of Moorea (17°30'S and 149°50'W) situated 18km northwest of Tahiti in the Society Islands, have been the primary study area for fieldwork since the beginning of dedicated research in 1991. Boat-based observations were conducted on both dedicated vessels and on platforms of opportunity. Additional shore and boat-based observations of humpback whales were begun in 1999 at Rurutu (22°30'S and 151°15'W) in the Austral Islands, approximately 570km SSW of Moorea. For the 1999 and 2000 seasons, the fieldwork was mainly conducted from the end of July to November for a total of 148 days.

Photo identification

Humpback whales were individually identified from photographs of the ventral fluke pattern (Katona and Whitehead, 1981). Although some of the research projects concerned used variation in other markings (notably dorsal fin shape or lateral pigmentation) to recognise individuals, only fluke photos were employed in the primary comparisons described here. Photos were taken with 35mm cameras equipped with zoom or telephoto lenses and either black and white print or colour slide film.

Regional photographic catalogues as well as some digital video images from the principal study sites were compared by participants at two four-day workshops convened at the University of Auckland, New Zealand in March 2000 and April 2001 (Donoghue and Baker, 2000; Anon., 2001). To

help establish the eastern extent of movement among whales seen in Oceania, additional comparisons were made between some of these sites and small sample sizes of photos from the eastern Pacific (Ecuador and Colombia) and the Antarctic Peninsula. All matches were confirmed by at least three participants at the workshop. A large catalogue of individual identification photographs from Eastern Australia (Kaufman *et al.*, 1993) was not considered at the workshops because of constraints on time and the variable quality of the published photographs. However, previous complete comparisons to this catalogue have established interchange between eastern Australia and New Caledonia (see below; Garrigue *et al.*, 2000).

To evaluate the relative magnitude of migratory interchange, the within-region return index and the between-region interchange index were calculated following Baker *et al.* (1986) and Calambokidis *et al.* (2001). The return index of within-region annual resights, was calculated as:

$$R_{ij} = M_{i,j} / (A_i * B_i) * 1000$$

Where

- A_i = number of whales marked in all the years before 2000;
- B_i = number of whales identified in 2000; and
- $M_{i,j}$ = number of whales marked in any previous years and resighted in 2000.

An interchange index of between-region resights was calculated as:

$$R_{ij} = M_{i,j} / (A_1 * B_2) * 1000$$

Where

- A_1 = number of whales identified in region A;
- B_2 = number of whales identified in region B; and
- $M_{i,j}$ = number of whales resighted in both regions.

The indices were considered to be zero when there were no whales sighted within or between regions (i.e. when $M_{i,j} = 0$).

RESULTS

The number of individual identification photographs varied considerably across regions (Table 1). The largest catalogues available for the comparison were for Tonga ($n = 337$ unique individuals), New Caledonia ($n = 206$) and French Polynesia ($n = 171$). The smallest catalogue was for New Zealand ($n = 6$). Larger catalogues exist for Colombia and the Antarctic Peninsula but were unavailable for the current comparison. In all, fluke photographs were available of 912 individual whales, of which 767 came from Oceania.

Comparison of 767 individual identification photographs represented by the regional catalogues revealed eleven matches among the five regions of Oceania; an additional two matches were made by non-systematic comparisons of dorsal fin photos. Matches were made between New Caledonia and New Zealand and Tonga; between Tonga and the Cook Islands; and between the Cook Islands and French Polynesia. Two of the matches were from sightings in a single winter season. One whale was seen in the Cook Islands on 19 and 23 August 1999, then in Tonga on 12 October 1999. One whale seen in French Polynesia in August 1998 matched an animal identified in the Cook Islands on 19 September 1998. The directional movements are varied and indicated no preferential direction (Table 2). One animal identified in New Zealand and New Caledonia has been resighted three times in the latter region. There

Table 1

Results of comparisons of photo-id catalogues among areas, with sample sizes of identified individuals used (*n*) and years of effort. Photos taken in 2000 were not compared to collections from Colombia or Ecuador. * Includes one match reported by Garrigue *et al.* (2000); † Does not include one match by dorsal fin; ‡ Does not include one match made by dorsal fin.

Area	<i>n</i>	Years	NZ	TG	CI	FP	AP	CO	EC
New Caledonia (NC)	206	1991-2000	2*	6†	0	0	0	0	0
New Zealand (NZ)	6	1994-2000		0	0	0	0	0	0
Tonga (TG)	337	1991-2000			2	0	0	0	0
Cook Islands (CI)	53	1998-2000				1‡	0	0	0
French Polynesia (FP)	171	1992-2000					0	0	0
Total for Oceania	767								
Antarctic Peninsula (AP)	60	1994-95						0	1
Colombia (CO)	20	1992-98							0
Ecuador (EC)	59	1996							

Non-systematic comparison to the published catalogue for eastern Australia resulted in four matches to New Caledonia, and one to Tonga (TG9103 and EO495, Kaufman *et al.* 1993).

Authors responsible for regional catalogues or comparisons: C. Garrigue and J. Greaves for NC; C.S. Baker, R. Constantine and M. Donoghue for NZ and TG; N. Hauser, H. Peckham and P. Clapham for CI; M. Poole, FP; A. Aguayo, C. Olavarria for AP; S. Caballero and L. Florez-Gonzalez for CO; J. Denkingier and C. Pairoa for EC.

were no matches between Oceania and either Ecuador, Colombia or the Antarctic Peninsula but sample sizes are small. One match made between Ecuador and the Antarctic Peninsula is not discussed further here.

Table 2

Directional movement of the resighted whales in between Tonga (TG), New Caledonia (NC), New Zealand (NZ), Cook Islands (CI), French Polynesia (FP). The * indicates a match with dorsal fin.

NC	→	TG	
1994		1999	
1		1	
1997		1996	
1*		1*	Female
1998		1999	
2		2	Males
1998		2000	
1		1	
NC	←	TG	
2000		1996	
1		1	Male
2000		1998	
1		1	Male
NZ	→	NC	
1994		1997, 1999, 2001	
1		1	Female
NZ	←	NC	
1998		1994, 1999	
1		1	Male
TG	→	CI	
1998		2000	
1		1	
TG	←	CI	
1999		1999	Male
1		1	
CI	←	FP	
2000		1997	Female?
1*		1*	
1998		1998	
1		1	

The between-region interchange indices were small in comparison to the within-region return indices from New Caledonia, Tonga and French Polynesia (Table 3). Only New Caledonia and New Zealand showed a relatively high resighting index suggesting a close migratory connection, although the sample size from New Zealand is very low. The absence of within-region returns in the Cook Islands could indicate that this region is part of an extended migratory corridor rather than a primary destination.

Table 3

Between-region interchange indices (normal text) and within-region return indices (in *italics*).

Area	NC	NZ	TG	CI	FP
New Caledonia (NC)	2.21	1.62	0.09	0	0
New Zealand (NZ)		0	0	0	0
Tonga (TG)			0.55	0.11	0
Cook Islands (CI)				0.00	0.11
French Polynesia (FP)					0.58

DISCUSSION

The results provide the first direct evidence of interchange or migratory movement among wintering grounds of Oceania. However, interchange was limited to adjacent wintering regions and the rate of interchange was considerably less than expected from the within-region return indices for New Caledonia, Tonga and French Polynesia. This limited interchange suggests that, with the possible exception of the Cook Islands, each region is demographically independent and should be recognised as an individual stock. Differences in within-region return indices could indicate differences in the strength of migratory fidelity or, more likely, differences in the abundance of whales visiting each region. The close migratory connection between New Caledonia and New Zealand is consistent with historical assumptions about migration patterns in eastern Group V (Dawbin, 1966). However, the absence of resightings between Tonga and New Zealand suggests a closer affinity of Tonga with Group

VI than previously assumed. Alternatively, a component of the Tongan stock could have been eliminated by intensive Soviet whaling in eastern Area V (see below).

The results also add to previously established connections between eastern Australia and the westerly component of Oceania. To date, four matches have been made between eastern Australia and New Caledonia (Garrigue *et al.*, 2000), two matches between New Caledonia and New Zealand (Garrigue *et al.*, 2000; this paper), and one match between Eastern Australia and Tonga (reported here for the first time; see notes in Table 1). No evidence was found of interchange between Oceania and Area I (western South America and the Antarctic Peninsula), although the sample sizes for the latter region were too small to conclude this with confidence. The direct evidence of movement within Oceania but not between Oceania and Group I is consistent with previous analyses of mitochondrial DNA gene flow among humpback whales in the Southern Hemisphere (Baker *et al.*, 1998; Caballero *et al.*, 2000; Olavarría *et al.*, 2000). Since no photographs were available of humpback whales from the high-latitude portions of Group V and VI at the time of the study, it is not possible to clarify the relationship between Oceania and the feeding grounds of the Antarctic.

Although rates cannot yet be quantified, the documented exchange between some regions has implications for stock assessment. Specifically, regional estimates of abundance will likely be positively biased because of the potential for whales to move among regions and be recorded more than once. On the other hand, the vast area involved (relative to the survey effort), in combination with heterogeneity in the distribution of individual whales, makes it unlikely that all whales were equally available for sampling. This could result in a negative bias of abundance for the region as a whole.

Currently there are preliminary estimates of abundance for only two regions of Oceania: New Caledonia (approximately 314 for 2000, Garrigue *et al.*, 2001) and Tonga (approximately 770 in the year 2000, Baker *et al.*, 2001). However, all of the observers participating in this comparison note from sighting density data that the abundance of humpbacks remains relatively low, and is clearly well below the levels that once supported large-scale commercial whaling. The apparent lack of recovery in Oceania contrasts sharply with the situation for neighbouring Eastern Australia (western Area V), and in Areas III and IV, where sighting surveys demonstrate consistently high rates of increase in recent years (Bryden *et al.*, 1990; Best, 1993; Bannister, 1994; Paterson *et al.*, 1994; IWC, 2000a). Although survey effort relative to humpback whales in New Zealand waters has been largely opportunistic, research and tourism directed at other cetaceans have consistently covered the former coastal habitat of humpbacks. It is clear from the small number of reported sightings that this species remains rare locally (Gibbs and Childerhouse, 2000). Indeed, New Zealand appears to be one of several areas where populations of mysticetes that were virtually extirpated by whaling have not been repopulated by immigration from elsewhere; this may be due to the effective loss of the cultural memory of a particular migratory route or destination (Clapham and Hatch, 2000).

With the exception of New Zealand, where humpbacks were hunted consistently from numerous shore stations (Dawbin, 1966), little whaling was conducted on the wintering grounds of Oceania itself during the 20th century. Humpbacks were taken in Tonga and near New Caledonia by 19th century whaling vessels and (following European

introduction) by Tongan families from the 1890's until 1978, using open boats and hand harpoons. Tongan whaling was small in scale, with annual catches prior to the early 1960's probably not exceeding 30–40 whales (Dawbin, 1959). No reliable data are available on the numbers taken by the more recent local Tongan hunting, but it is known that the hunt focused on mothers and calves, and struck and lost rates of up to 3:1 (relative to whales killed and secured) have been estimated (IWC, 1981). Nine whales have been reported to be killed by locals at Rurutu between 1930 and 1959 (M. Poole, unpublished data).

However, it is now clear that thousands of humpbacks were removed from Oceania by illegal Soviet hunting in the Antarctic; indeed, almost 13,000 humpbacks were taken in a single season (1959/60) from western Area V and eastern Area VI feeding grounds (Mikhalev, 2000). It is therefore not surprising that abundance in wintering grounds of Oceania remains low. Until the locations of all the illegal Soviet catches are published, the total number of humpbacks killed in Area VI will remain uncertain. In light of this, it is suggested that an assessment of current trends and abundance in Oceania is critical to understanding variability in recovery of Southern Hemisphere humpback whales. The work summarised here represents the preliminary framework for such an assessment.

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Calls recorded from North Pacific right whales (*Eubalaena japonica*) in the eastern Bering Sea

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ABSTRACT

Calls from North Pacific right whales (*Eubalaena japonica*) were recorded in the eastern Bering Sea during a visual and acoustic survey aboard the US Coast Guard buoy tender *Sweetbrier*, in July 1999. Calls were commonly detected to 20km, and in one case approximately 30km, via deployment of arrays of directional sonobuoys. Acoustic detections (clusters of right whale calls separated by time and location) numbered 26, but only five right whales were seen. Only one right whale produced calls while under visual observation. The types of calls recorded from North Pacific right whales were similar in duration and frequency to calls recorded from right whales in the South Atlantic. The predominant call type (85%; 436 of 511 calls) was the 'up' call, a signal sweeping from about 90Hz to 150Hz in 0.7s. Two call types are described as 'down' and 'constant' calls, based upon nomenclature established for southern right whales (*Eubalaena australis*). One call type, the 'down-up' was unique to the North Pacific repertoire. Right whales commonly produced calls in series lasting several minutes and then became silent for an hour or more, with some animals not calling for periods of at least four hours. Other cetaceans detected acoustically by 'random' sonobuoy deployments during the cruise included fin whales (19 times), killer whales (3 times) and sperm whales (once).

KEYWORDS: NORTH PACIFIC RIGHT WHALE; ACOUSTICS; ACOUSTIC-SURVEY; MONITORING

INTRODUCTION

A two-week cruise was conducted in July 1999 in association with aerial surveys to find and photograph North Pacific right whales (*Eubalaena japonica*) in the eastern Bering Sea, where they have been seen each July since 1996 (Goddard and Rugh, 1998; Tynan, 1998; 1999; Moore *et al.*, 2000; LeDuc *et al.*, 2001; Tynan *et al.*, 2001). The overall goal of the cruise was to biopsy right whales, collect aerial photographs and, if possible, detect and locate whales via localisation of acoustic calls (LeDuc *et al.*, 2000). Although calls of southern right whales (*Eubalaena australis*) are well documented (e.g. Clark, 1982; 1983), there are only a few descriptions of calls for the North Atlantic species (*Eubalaena glacialis*; e.g. Gillespie and Leaper, 2001; Matthews *et al.*, 2001) and none for North Pacific right whales. A goal of the acoustics work was to acquire baseline recordings of North Pacific right whale calls and to evaluate the potential for long term acoustic monitoring of the eastern Bering Sea using autonomous seafloor-moored recorders. Autonomous recorders can now record continuously for a year or more and will provide a means to ascertain seasonal occurrence and estimate minimum population size of this critically endangered species in the eastern Bering Sea.

METHODS

The vessels used in this study were the United States Coast Guard buoy tender, *Sweetbrier* and a Rigid Hull Inflatable Boat (RHIB) launched from the *Sweetbrier*. The science team consisted of five personnel, four visual observers and one acoustics observer. DIFAR (DIrectional Frequency Analysis and Recording) sonobuoys were deployed when whales were seen, and at intervals when they were not, to detect right whale calls and direct the ship towards the whales. When right whales were seen, an array of four or more sonobuoys was deployed to localise the source of any

calls. Each array was deployed with the best practical geometry, which meant spacing sonobuoys a minimum of about 2km apart. Actual array geometry was limited by radio reception range and the track of the ship and RHIB relative to the whales. The ship's track was determined by the cruise objectives, which were to: (1) biopsy right whales; (2) collect aerial photographs for photo-identification; (3) record right whale calls; and (4) conduct a visual line transect survey.

All of the sonobuoys used for right whale recording were type 53 DIFAR, which transmit three multiplexed signals on a VHF radio carrier providing direction finding capability accurate to about 2°SD. Systematic errors of about 2°SD are also associated with each sonobuoy, but these were corrected using the ship as a sound source at a known location. Sonobuoy hydrophones were set to a depth of 28m (90ft) and secured with duct tape to prevent accidental release of additional hydrophone wire. Buoy life was set to eight hours, although the actual recording period was typically determined by the radio reception range. The frequency response of these sonobuoys increases by roughly 6dB per octave from 10Hz to 1kHz, flat from 1kHz to 2.4kHz and a 30dB/octave roll off from 2.4kHz to 4kHz, the effective upper limit of the recording capability. The spectrograms shown have not had this frequency response removed.

The radio receiving and recordings system had a flat frequency response across the band of interest. Radio signals were received on a *Ringo Ranger* omni-directional antenna, mounted at 19m (61ft) on a mast cross tree, and connected via a mast pre-amp and RG-8 cable to the receivers. The five radio receivers used were specially constructed and calibrated by *GreeneRidge Sciences Inc*¹. Sonobuoy radio reception was typically strong to 18km (10 n.miles), and at times extended to roughly twice that distance. Radio reception distance did not appear to be effected by sea state,

¹ Use of company or trade names does not imply endorsement.

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suggesting that atmospheric conditions (temperature and humidity stratification) were the dominant cause of range variability. Data were recorded on *Sony* model TCD-D8¹ and model PCM-M1¹ digital audio tape (DAT) recorders, sampling at 48kHz and 44.1kHz respectively. Call localisation was performed using de-multiplexer software provided by *GreeneRidge Sciences Inc*¹ and direction finding software written by the lead author, based on the methods of D'Spain (1994). Scrolling spectrograms were monitored at sea using *SpectraPlus*¹ commercially available software.

All tapes were re-analysed post-cruise by the lead author to detect and classify calls. Call identification and classification was carried out using scrolling spectrograms combined with listening and localisation of all calls. Scrolling spectrograms are particularly helpful for detection of the lowest frequency calls where listening alone may be inadequate. Call localisation was achieved primarily by plotting multiple DIFAR sonobuoy bearings to each call, complimented by arrival time localisation, comparison of call amplitudes, and dispersive mode propagation.

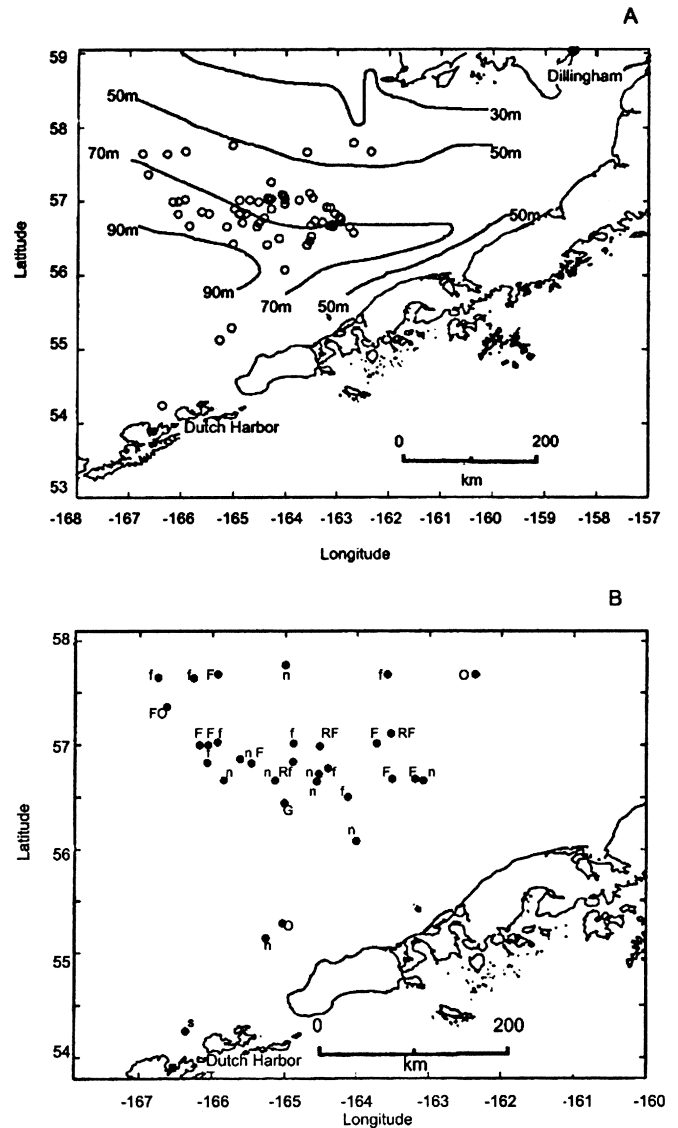
Listening and call localisation were helpful in separating fin whale (*Balaenoptera physalus*) and humpback whale (*Megaptera novaeangliae*) calls from right whale calls. All fin whale calls that were recorded in the Bering Sea sweep down in frequency, while the most common right whale call in this region sweeps up, making them easy to separate. Humpback whales typically produced higher frequency calls than right whales. If a call was of a type similar to that known from both humpback and right whales, it was classified to species according to its geographic location and the presence of calls more clearly identifiable as belonging to one species or the other. The start and end points of each call were picked visually with a computer cursor on a spectrogram display and durations rounded to the nearest 0.1 second. On a few occasions, there were detections of single calls or just a few indistinct calls which could not readily be associated with any species. When these could not be localised to the known location of any species, no detection was scored in any category.

RESULTS

Sonobuoy deployments

Sixty-six sonobuoys were deployed during the cruise (Fig. 1a); 34 were set out during times when a whale/whales of any species had been recently seen or a right whale had been acoustically detected; 32 buoys were launched 'at random', when no whales had been recently observed. Of the 34 buoys deployed near the time of a whale sighting, 23 were deployed as right whale localisation arrays, while 11 buoys were deployed near the time of visual sightings of fin, humpback or killer whales (*Orcinus orca*). Except for the first buoy launched as the ship was leaving Dutch Harbour, all were deployed in shallow inner (<50m) and middle shelf (50-100m) water in the eastern Bering Sea.

Recordings from the 32 sonobuoys deployed 'at random' (Fig 1b), resulted in detections of right whales (3 times); fin whales (19 times); killer whales (3 times); sperm whales (once); and calls from an unknown biological source, possibly a gray whale (once). Humpback whales were acoustically detected on six occasions, although only on sonobuoys deployed after a whale sighting. Fin whale calls were frequency downswept pulses of about 0.8s duration as commonly recorded elsewhere in the world (e.g. Moore *et al.*, 1998), although many were at higher frequencies (sweeping from 120Hz to 90Hz) than is typical for fin whale



R = right f = occ.fin F = many fin O = orca n = none G = gray? s = sperm

Fig. 1. Locations of 66 sonobuoys deployed during the cruise in relation to bathymetry (a); and locations for the 32 sonobuoys deployed 'at random' when no whales were seen, with symbols denoting the whale species detected, or none (b).

pulses (Edds, 1988). The killer whale calls were similar to those reported for resident-type animals recorded elsewhere (Ford, 1991; Deeke *et al.*, 1999). The single deep-water buoy near Dutch Harbour recorded a sperm whale producing 'slow' clicks as is typical of a male (Whitehead and Weilgart, 1990). No calls were recorded from nine (28%) of the deployments. These random deployments give an indication of likely detection rates for different species, given that each buoy was recorded for about one hour.

Right whale detections

There were 26 occasions when right whales were detected acoustically including both the random sonobuoy deployments (3 encounters) and during the deployment of four arrays (23 encounters), where an acoustic 'encounter' is defined as a call or series of calls at a new location. Right whales were seen on four occasions (total of five animals), sometimes while following acoustic bearings to calls. Of note, post-cruise analyses of the acoustic data always revealed the presence of multiple right whales in the vicinity of each sighting. While acoustic detections resulted in

re-directing the ship to the general search area where right whales were present, it was unclear if any of the whales seen were the same animals that produced the calls which caused the ship search to be re-directed. Only on one occasion (11 July) was a right whale calling while under direct visual observation. Calls from this whale were readily detected at a range of 19km and appear to have been detected out to at least 30km, as estimated by propagation mode dispersion.

Post-cruise analysis of the acoustics data during each right whale sighting revealed widely separated acoustic localisations over periods too short to allow for a single animal to have moved to each of the acoustic call locations (Fig. 2). It was not possible to definitively correlate the locations of the call clusters as a swim track. Some of the 26 encounters are likely multiple call series from the same whale on the same day, but this cannot be determined. The acoustic right whale locations observed on 17 July require a minimum of five right whales assuming typical right whale travel speeds.

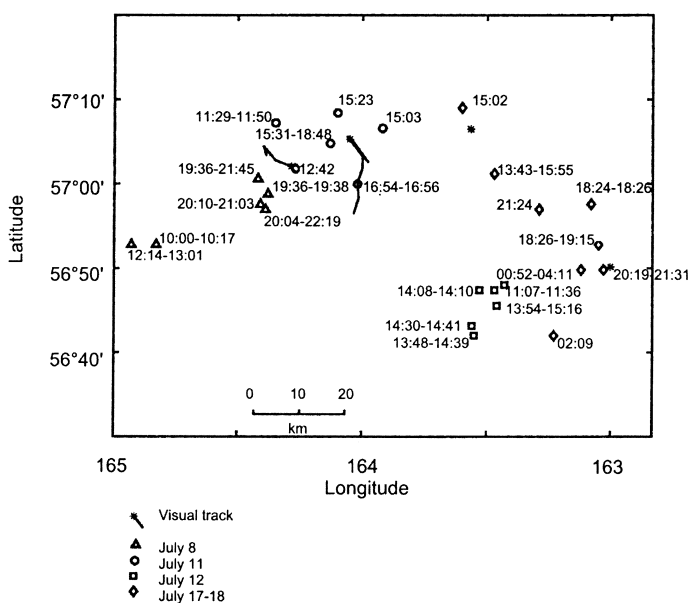


Fig. 2. The 26 North Pacific right whale acoustic detections are shown with a symbol corresponding to each array, with local times posted for each encounter. The acoustic encounter locations were determined by crossing bearings from a directional sonobuoy array. The visual right whale tracks are shown with an asterisk at the four initial locations and visual track lines are shown when available. The only match between visual and acoustic locations occurred at 16:54-16:56 on July 11. Tracks are shown for both of the two animals seen on this occasion although the animals were widely separated at the time of the acoustic calls.

Calls were usually produced in series at rates of several calls per minute, thus calls which were not of the most common 'up-type' were identified as being produced by right whales only if the call source was localised from the same location as the 'up' call. For example, 'high', 'hybrid' or 'pulsive' calls (as described in Clark, 1983) could have been missed if produced without the typical 'up' call in the same call series. Similarly, atypical sounds, such as a broadband 'slap' or 'gunshot' sounds (Clark, 1983), were commonly recorded during this cruise, but were typically associated with humpback whales and were not found to occur at the same location as typical 'up' calls. If right whales did produce such sounds, but not in association with right whale 'up' calls, they may not have been attributed to

right whales. The one call series produced while the calling whale was under direct visual observation on 11 July, contained only 'up' calls.

Call types

The 511 calls considered to be from right whales were classified into five categories: (1) up; (2) down-up; (3) down; (4) constant; and (5) unclassified (Fig. 3). The 'up' call was the predominant type, comprising 85% ($n = 436$) of all calls recorded. 'Up' calls were typically produced in a series of 10-15 calls (Fig. 4), followed by silence lasting an hour or more. A very similar call type, the 'down-up', differed in that it sweeps down in frequency for 10-20Hz before becoming a typical 'up' call (Fig. 3b). 'Down-up' calls comprised 5% ($n = 26$) of the call sample and most ($n = 20$) were recorded during only two of the 26 acoustic encounters, these two call series possibly being from the same animal. The 'down' calls ($n = 18$; 3.5% of all calls) were usually interspersed with up calls (see Fig. 4), as were 'constant' calls ($n = 27$; 5% of all calls). The constant frequency calls could be further sub-divided into those consisting of a single frequency tonal (2%) and those where the frequency wavers up and down by about 10Hz (3%; Fig. 4a). The remaining 1.5% of calls did not readily fit into any of the above categories.

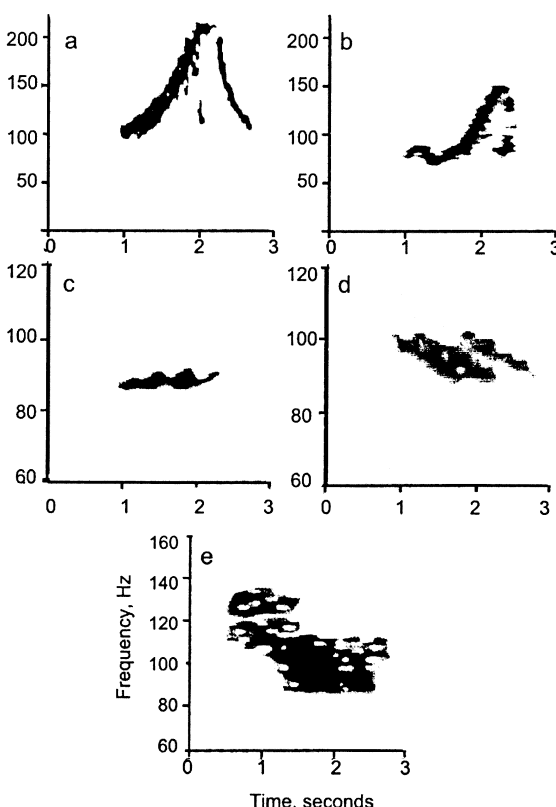


Fig. 3. Spectrograms illustrate representative examples of the call type classifications used in this study. The call types are (a) up; (b) down-up; (c) constant-tonal; (d) constant-waver; (e) down. All spectrograms use a 0.5 second FFT length with 87.5% overlap; note the different frequency scales. Dispersive propagation mode artifacts are visible in all but (c).

Descriptive statistics of the 'up' calls are provided in Figs 5 and 6. Typically, 'up' calls sweep from about 90Hz to 150Hz in 0.7s. Sweep rates ranged from 35 to 150Hz/s (median = 63). The 'down' and 'constant' calls are somewhat lower in frequency than the 'up', the average start frequency for the 'down' call being 118Hz (SD = 13), the

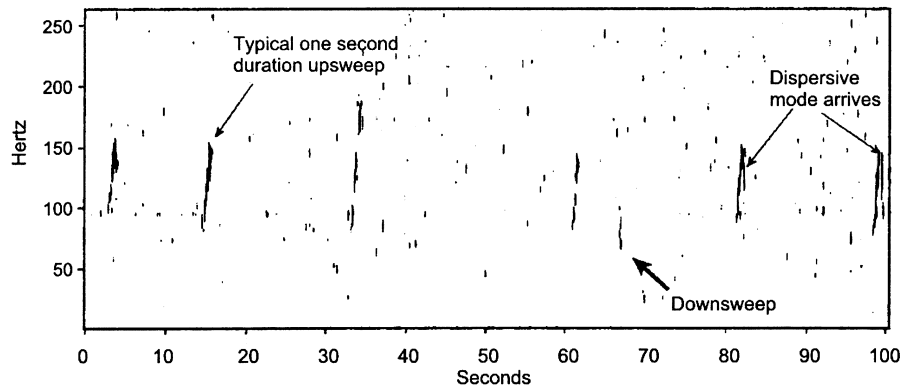


Fig. 4. This call series shows North Pacific right whale 'up' calls, with a 'down' call and examples of dispersive propagation mode arrivals of 'up' calls.

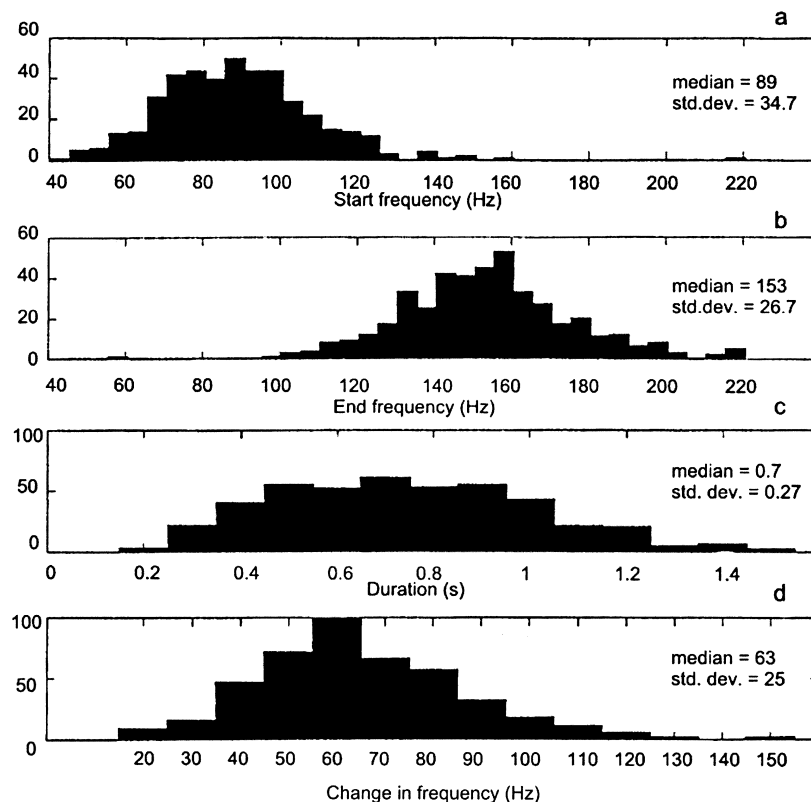


Fig. 5. Descriptive statistics for the 436 'up' calls: start frequency (A) end frequency (B) duration (C) and change in frequency over the course of the call (D).

end frequency 86Hz (SD=15) and duration 0.8 seconds (SD=0.3). The 'constant' calls have an average frequency of 94Hz (SD=22) and an average duration of 1.6 seconds (SD=0.8). The durations of the constant calls appear to be longer than that of the 'up' calls, but this may be an artifact caused by the acoustic propagation modes rather than a longer sound source duration.

DISCUSSION

Call types

This study provides the first description of North Pacific right whale calls as well as a measure of their calling activity level in the eastern Bering Sea. Nearly all previous descriptions of right whale calls are from recordings at a breeding and nursery area in Argentina (Clark, 1982; 1983). Three of the call types reported here are described using the same nomenclature as Clark (1983), the down-up call being

the exception. In the Argentine study, male and female right whales had similar call repertoires and whale surface-activity level, group size and sexual composition were correlated with the types of calls recorded. Description of calls for North Atlantic right whales are sparse, including a short summary on a phonograph record (Schevill and Watkins, 1962) and a report where calls were classified only as moans (>100Hz), low frequency (LF ~ 70Hz), or 'gunshots' (Matthews *et al.*, 2001). In the latter study, moans were associated with larger whale groups and were more frequently recorded at night.

Acoustic versus visual detection

Passive acoustics techniques are now commonly used to detect and assess cetaceans. Comparatively long-term deployments of autonomous recorders are often used to detect and sometimes track mysticete whales (e.g. McDonald *et al.*, 1995; Stafford *et al.*, 2001), while towed

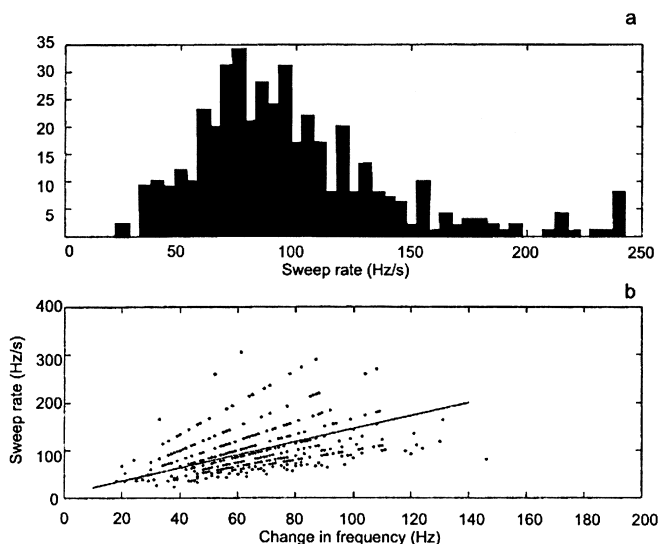


Fig. 6. The sweep rate for the 436 ‘up’ calls is depicted. The apparent alignments in the scatter plot are caused by the rounding of the call duration to the nearest 0.1 second. The sweep rate is greater for those calls sweeping a greater frequency range, resulting in calls nearly the same length regardless of the change in frequency.

arrays are commonly used for odontocete detection (e.g. Gordon *et al.*, 2000; Leaper *et al.*, 2000). Studies that incorporate passive acoustics always benefit from the extended temporal and spatial range of sampling, as summarised over 15 years ago by Thomas *et al.* (1986).

Right whales were routinely detected to about 20km, roughly twice the furthest distance of visual detections. Given the longer detection ranges of acoustic methods, it is perhaps not surprising that more right whales were detected acoustically than visually during the *Sweetbrier* cruise. In addition, given the brief period (9.5 hours) during which right whales were kept under both acoustic and visual observation it is not surprising that only one of the 26 acoustic encounters occurred with the calling animal under direct visual observation (Table 1). Even if visual observations had been maintained for longer periods, approaches by the ship for biopsy sampling likely altered whale behaviour and thus the result of one acoustic encounter in 9.5 hours of observation is not necessarily typical of undisturbed animals. Finally, while as few as five whales could have been responsible for all 26 of the acoustic encounters, it is our belief that more than five whales were present because it is unlikely each animal within acoustic range produced calls during the sampling periods.

Table 1

Summary of acoustic and visual monitoring, after a North Pacific right whale was detected either visually or acoustically. Only one call series (on July 11th) was recorded from a visually monitored whale during a total of 9.5 hours of direct visual observation on all whales. The 56 hours of acoustic monitoring in the presence of one or more right whales resulted in the 26 acoustic encounters shown in Figure 2.

Date	Acoustic contacts (no.)	Visual contacts (no.)	Acoustic monitoring (hrs)	Visual observation (hrs)
8 July	6	1	14	2
11 July	6	2 (together initially)	15	3
12 July	6	1	8	4
17 July	8	0	16	0
18 July	0	1	3	0.5
Total	26	5	56	9.5

Calling activity, detection range and estimation of number of calling whales

Right whales in the eastern Bering Sea nearly always called in bouts ranging in duration from a few minutes to over an hour. Overall, calling activity was low, usually a series of ‘up’ calls lasting 5-10 minutes followed by an hour or more of silence. This calling pattern is similar to the ‘moan cluster’ reported in Matthews *et al.* (2001), but different from that described for Southern right whales (Clark, 1983). In the Argentine breeding area, right whale calling activity was correlated with group size and composition. Furthermore, several additional and more complex call types were described. These differences in calling activity could be attributable to species differences, but are more likely a function of behaviour. In the breeding and calving areas offshore Argentina, right whales are involved in a suite of social behaviours (Payne, 1986), with ‘the complexity of the social context directly related to the complexity of the sounds made’ (Clark, 1983). In the eastern Bering Sea, right whales are more typically focused on feeding (Tynan, 1999), although mating activity has been witnessed there (SEM). Thus, a simple series of ‘up’ or ‘contact’ (Clark, 1983) calls is likely sufficient to keep whales in acoustic contact. Indeed, the graded series signalling paradigm of Morton (1982) predicts this relationship between signalling complexity and call types.

Dispersive propagation modes

The relatively shallow and nearly constant water depth in the eastern Bering Sea provides a wave-guide for the low frequency acoustic energy of the right whale calls. The interaction of reflected energy travelling in the horizontal direction results in energy pulses called modes each travelling with a different velocity (Urick, 1983). Mode propagation is dispersive, which means lower frequencies travel more slowly than higher frequencies under these propagation conditions. Thus, while the mode 1 arrival of a right whale call may appear as an upsweep, the mode 2 arrival may appear as a downsweep due to this dispersive propagation phenomena.

The differential arrival times of the first two propagation modes and the dispersive nature of the mode 2 arrival are seen in spectrograms (Fig. 7). The increasing separation between mode 1 and mode 2 with increasing propagation distance is apparent. Four mode arrivals is the maximum number observed with the right and fin whale calls recorded during this cruise and it should be noted that not all calls show clear mode arrivals. Mathematical models of acoustic mode propagation have become routine to the extent that the models themselves are scarcely mentioned in papers which use such techniques to estimate seafloor geo-acoustic parameters and water column sound speed profiles (i.e. Potty *et al.*, 2000). Knowledge of the bathymetry is the single most important parameter and a relatively flat seafloor simplifies modelling accuracy (Medwin and Clay, 1998).

The likely reason why some calls show mode arrivals more clearly than others is the depth of the whale when the call was produced and the depth of the receiver, rather than simply the range from the calling whale. Further analyses of these propagation modes should allow calculation of the range to the call with accuracy on the order of 1km. While it will remain a difficult problem to estimate abundance of whales from acoustic data alone, knowledge of detection range and change in detection range with changes in ambient noise will be an important step towards the goal of better estimating the relative abundance of whales with autonomous seafloor recorder data.

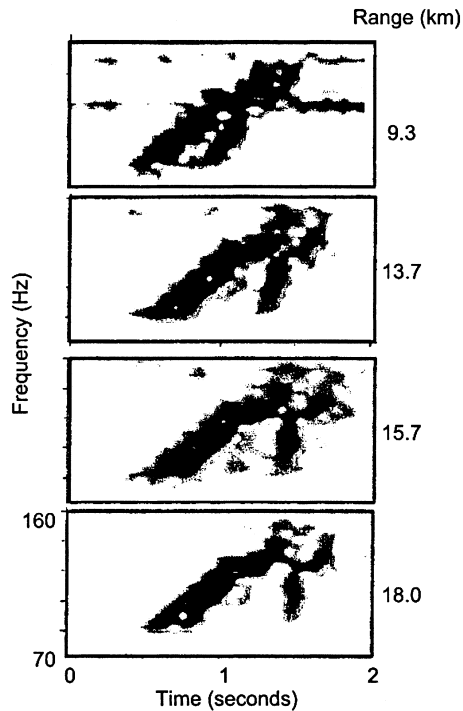


Fig. 7. A right whale call as recorded on four sonobuoys while under visual observation on 11 July at 16:54; water depth = 70-73m. The increasing separation between mode 1 and mode 2 with increasing propagation distance is apparent and dispersion of mode 2 is clearly seen where the lower frequency energy travels more slowly.

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Abundance, range and movements of a feeding aggregation of gray whales (*Eschrichtius robustus*) from California to southeastern Alaska in 1998

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ABSTRACT

This study documents the range, abundance and movements of a feeding aggregation of gray whales (*Eschrichtius robustus*) in the Pacific northwest. Identification photographs were collected by eight collaborating organisations between March and November 1998. Surveys extended between northern California and southeastern Alaska. Effort was variable by region and was concentrated off the northern Washington coast and Vancouver Island. Of 1,242 occasions when suitable photographs of gray whales were obtained in 1998, 155 unique whales were identified. Each individual was photographed an average of 8.0 times (SD = 8.4, range 1-42) and the average tenure of whales seen multiple times was 56 days (SD = 41, range 1-170). Whales seen longer than three months generally were seen in multiple regions. Movements among regions in 1998 were documented for 57 whales with the most frequent interchange among three adjacent areas from northern Washington to central Vancouver Island. The overall pattern of movements among regions was complex; whales were not always moving in the same direction at the same time of year. Movements within 1998 among more distant locations did occur but were less frequently observed. Total distances between resighting positions for individual whales ranged from < 1 to 526 n.miles. Most whales photographed in 1998 had been identified in previous years when compared to photographs collected by some of the collaborators. At least 86 (55%) of the whales identified had been seen previously. The rate of inter-year resightings was highest for whales identified off northern Washington and three areas off British Columbia (from southern Vancouver Island to north of Vancouver Island). In these areas, from 70-100% of the whales seen in each region had been photographed previously. Mark-recapture abundance estimates based on comparisons to samples in 1996 and 1997 were 181 and 179, respectively. The management implication for these whales has become controversial due to the resumption of whaling by the Makah tribe in northern Washington, an area used by both migrating and feeding whales. This research shows that there are a few hundred gray whales that range in summer months from at least northern California to southeastern Alaska. The mechanism by which these animals are recruited into this group and the degree to which they should be managed as a separate unit from the overall population is not resolved.

KEYWORDS: GRAY WHALE; PHOTO-ID; PACIFIC OCEAN; FEEDING GROUNDS; MOVEMENTS; SITE FIDELITY; MARK-RECAPTURE; ABUNDANCE ESTIMATE; WHALING-ABORIGINAL

INTRODUCTION

Gray whales make one of the longest migrations of any mammal between their winter breeding grounds off Baja California, Mexico, and their feeding grounds in the Bering and Chukchi Seas. Migrations along the Pacific northwest coast occur in December and January when the animals are southbound and again in the spring when the whales are northbound. Outside these migratory time periods, summer feeding aggregations of gray whales have been reported in a number of areas along the coasts of California, Oregon, Washington and British Columbia (Howell and Huey, 1930; Gilmore, 1960; Rice, 1963; Rice and Wolman, 1971; Patten and Samaras, 1977; Flaherty, 1983; Darling, 1984; Murison *et al.*, 1984; Nerini, 1984; Sumich, 1984; Malloné, 1991; Avery and Hawkinson, 1992; Calambokidis *et al.*, 1992; 1994; Weitkamp *et al.*, 1992). These animals have been referred to as summer or seasonal residents (Pike, 1962; Darling, 1984; Murison *et al.*, 1984; Weitkamp *et al.*, 1992) and more recently as the 'Pacific Coast Feeding

Aggregation' whales (National Marine Fisheries Service [NMFS], 2001).

In the early 1970s, photographic identification research demonstrated that many of the gray whales that would remain off Vancouver Island to feed through late spring and summer were the same individuals that returned to the same area each year (Hatler and Darling, 1974; Darling, 1984). Similarly, gray whales photographically identified off Washington State and northern British Columbia from late spring to autumn were also found to return annually (Calambokidis *et al.*, 1994). These whales appear to be part of the overall eastern gray whale population and generally arrive and depart from these feeding grounds concurrently with the migration to and from the wintering grounds. Gray whales in these regions have been observed feeding on a variety of prey including herring eggs/larvae, crab larvae, amphipods, mysids and ghost shrimp (Murison *et al.*, 1984; Nerini, 1984; Oliver *et al.*, 1984; Weitkamp *et al.*, 1992; Duffus, 1996; Darling *et al.*, 1998). Movements over distances of less than 100km and changes in distribution of

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animals in response to shifting prey types have been documented (Darling, 1984; Darling *et al.*, 1998). Darling (1984) suspected gray whales seen along the coast of British Columbia in summer months were part of a larger 'northwest coast' sub-population that numbered at least 100 animals.

Information on the status, range and movements, and abundance of these whales is crucial in the management of gray whales especially due to the resumption of whaling by the Makah Tribe in northwest Washington State. Although the current management plan for hunting of gray whales calls for targeting migratory animals, it may be difficult to avoid taking whales from this seasonal feeding aggregation (Quan, 2000). It is currently unclear whether the feeding aggregation of gray whales in the Pacific northwest should be treated as a separate population. Genetic differences have not been found to date between these animals and the overall population (Steeves *et al.*, 2001).

This paper examines the range of movements and tenure of individual gray whales between spring and autumn 1998 based on photo-identification research conducted collaboratively in many regions between northern California and southeastern Alaska. With data on these whales from previous years, this paper also examines site fidelity, interchange and estimate of abundance.

MATERIALS AND METHODS

Identification photographs of gray whales were collected by eight collaborating organisations between 12 March and 18 November 1998 from northern California to southeastern Alaska (Table 1). Effort by region was variable with most intensive coverage along the southern and western coast of Vancouver Island. Effort and identifications were grouped into 12 regions (Fig. 1) based on bodies of water and operating areas for surveys.

Photographic identification methods

Although a variety of vessels were used in different areas, most of the effort was conducted using small vessels (< 10m) and photo-identification methods were similar. Whales were approached slowly from the side at a distance of 50-100m. Both left and right sides of the dorsal region around the dorsal hump and the flukes of gray whales were photographed if possible. Most groups used 35mm cameras usually equipped with 300mm lenses and high-speed black and white negative film. Markings used to distinguish whales included pigmentation of the skin, mottling and scarring, which varied among individuals and have provided a reliable means of identifying gray whales over periods of

Table 1
Summary of areas of effort, participating organisations, number of identifications and dates of identifications in 1998.

Region	Region code	Description	Organisations	Unique IDs	Unique IDs	Dates of identifications	
						Begin	End
Northern California	CA	Eureka to Oregon border with most identifications from	Humboldt State Univ. (HSU) Cascadia Research Collective (CRC)	27	15	21 Jul. 1998	10 Oct. 1998
Oregon coast	OR	Primarily central coast near Depoe Bay and Newport, OR	Humboldt State Univ. (HSU) Cascadia Research Collective (CRC)	46	18	29 Jul. 1998	4 Oct. 1998
Grays Harbor and S Washington	GH+	Includes waters inside Grays Harbor and coastal waters along the S Washington coast	Cascadia Research Collective (CRC)	59	7	21 Mar. 1998	11 May 1998
N Washington coast	NWA	Northern outer coast waters with most effort from Cape Alava to Cape Flattery	National Marine Mammal Laboratory (NMML) Cascadia Research Collective (CRC)	46	21	6 Jun. 1998	18 Nov. 1998
US Strait of Juan de Fuca	SJF	US waters east of Cape Flattery extending to Admiralty Inlet (entrance to Puget Sound)	National Marine Mammal Laboratory (NMML) Cascadia Research Collective (CRC)	35	15	17 Aug. 1998	11 Nov. 1998
Northern Puget Sound	NPS	Inside waters and embayments from Edmonds to the Canadian border	Cascadia Research Collective (CRC)	27	6	12 Mar. 1998	20 May 1998
Southern Puget Sound	SPS	Central and southern Puget Sound (S of Edmonds) and Hood Canal	Cascadia Research Collective (CRC)	6	4	18 Mar. 1998	17 Nov. 1998
Boundary Bay	BB	Canadian inside waters in and around Boundary Bay, only a single survey	Vancouver Aquarium	3	3	7 Apr. 1998	7 Apr. 1998
S Vancouver I.	SVI	Canadian waters of the Strait of Juan de Fuca along Vancouver I. from Victoria to Barkley Sound, most effort along the West Coast Trail	West Coast Whale Research Foundation (WCWRF) Juan de Fuca Express Univ. of British Columbia (UBC) National Marine Mammal Laboratory (NMML) Cascadia Research Collective (CRC) Dep't of Fisheries and Oceans (DFO)	487	61	4 May 1998	9 Oct. 1998
Central Vancouver I.	CBC	Central portion of the western coast of Vancouver I. with heaviest effort in and around Clayoquot Sound	West Coast Whale Research Foundation (WCWRF) Univ. of Victoria (UVIC)	401	57	13 Jun. 1998	3 Sep. 1998
N of Vancouver I., BC	NBC	British Columbia waters north of Vancouver I., with principal effort around Cape Caution	Coastal Ecosystems Research Foundation (CERF)	100	22	3 Jul. 1998	11 Sep. 1998
SE Alaska	SEAK	Waters of southeastern Alaska with the only effort in the vicinity of Sitka (single survey)	Cascadia Research Collective (CRC)	4	4	8 Nov. 1998	8 Nov. 1998
All areas				1,241	155	12 Mar. 1998	18 Nov. 1998

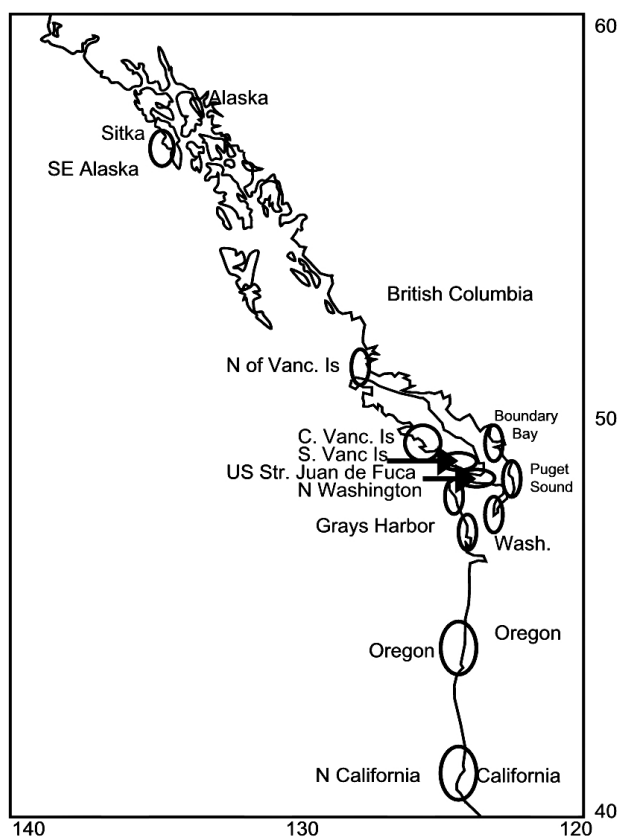


Fig. 1. Study area showing principal areas of effort.

deemed of suitable quality but did not match the existing catalogue (compared by two independent matchers) were assigned a new identification number.

Information on sightings from previous years came from two sources. Cascadia's catalogue from past years consisted of 835 records of 171 unique gray whales identified between 1984 and 1997. While most of these identifications were from Washington State, including Puget Sound and inland waters, small samples were also collected off California and southern British Columbia. These photographs were collected by Cascadia Research personnel or other collaborating scientists and naturalists. Additionally, individual research groups participating in the 1998 collaboration provided information on past years' sightings of animals they saw in 1998 (they did not have access to the entire collection of 1998 photographs). Since these groups only compared photographs from their own regions to its past collections, there was not a complete comparison among these collections. The proportions of individuals identified in previous years, therefore, are reported as minimums.

RESULTS

Sighting patterns and movements within 1998

From the 1,241 occasions when suitable photographs of a gray whale were obtained in 1998, 155 were identified as unique whales (Table 1). Each individual was photographed from 1-42 times (mean 8.0, SD = 8.4). The largest number of individuals were identified off the southern coast of Vancouver Island, especially in June and July, and from central Vancouver Island around Clayoquot Sound in July and August (Table 2).

Of the 155 identified whales, 117 (75%) were photographed on more than one day. Time between multiple sightings of individual whales ranged from 1-170 days (average of 56 days, SD = 42). Whales seen with a tenure of over three months generally were seen in multiple regions. The whale (ID# 192) seen over a 170 day period was first seen on 4 May and was resighted 42 times up to 21 October: it was seen from 4 May to 6 July off the West Coast Trail of southern Vancouver Island; 9 to 31 July in the Clayoquot Sound vicinity of central Vancouver Island (with a single resighting off the West Coast Trail on 24 July); 6 to 27 August off the West Coast Trail; and then from 5 September to 21 October, it was seen repeatedly off the northern Washington coast.

close to 20 years (Darling, 1984; Darling *et al.*, 1998). The relative spacing between the knuckles along the ridge of the back behind the dorsal hump was also used to find photographic matches.

Photographic matching

Comparison of whale photographs to determine matches was made in a series of steps. First, the negatives of gray whales were examined and the best image of the right and left side of each whale (for each sighting) was selected and printed (17.8 x 6.4cm). To determine the number of whales seen during the season, all photographs from 1998 were compared to one another to identify whales seen on multiple days. Finally, a comparison was made between the best photograph in 1998 and Cascadia's catalogue of whales seen in past years (see below). Whale photographs that were

Table 2
Number of unique individual gray whales photographed in each region by month in 1998.

	Month									All months
	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	
Northern California					2	1		13	1	15
Oregon coast					4	17		1		18
Grays Harbor and S Washington	4	7	1							7
N. Washington coast				1	12	6	8	5	1	21
US Strait of Juan de Fuca						1	2	9	7	15
Northern Puget Sound	6	4	1							6
Southern Puget Sound	1							1	2	4
Boundary Bay		3								3
S Vancouver I.			8	40	45	15	30	9		61
Central Vancouver I.				17	40	42	7			57
N of Vancouver I., BC					18	14	3			22
SE Alaska									4	4
All areas	11	14	10	54	88	81	43	37	15	155

Movements among regions in 1998 were documented for 57 whales (Table 3): 38 seen in two regions; 18 in three regions; and 1 in four regions. The most frequent interchange was among three adjacent sites from northern Washington to central Vancouver Island (Table 4a). The overall pattern of movements among regions was complex (Fig. 2). Whales were not always moving in the same direction at the same time of year. Despite the wide variations in movement patterns of different individuals, a few patterns could be discerned. A high concentration of whales identified off southern Vancouver Island in June (40 individuals) and July (45) then appeared to disperse somewhat with 19 transits observed from this area north to Clayoquot Sound in July and, to a lesser degree, August. Some animals also moved

south from southern Vancouver Island at this same time with 10 transits to the Washington coast and several more toward Oregon and California (arriving in later months). In August, the number of whales in the Clayoquot Sound area (42 individuals) peaked and a high number of transits were observed late in the month and extending into September from this area back to southern Vancouver Island (14 transits) as well as other areas primarily to the south.

Movements within 1998 among distant locations were rare. Only one whale was found to move from northern California to another location: whale ID# 76 was seen multiple times between 12 June and 9 July off southern Vancouver Island and was not observed again until 10 October when it was seen feeding off Point St George in

Table 3
Summary of identifications and resighting rates of gray whales in 1998 by region.

Region	Unique IDs	No. seen more than once in 1998	No. seen in same region in a previous year	No. seen in another region in 1998	No. seen in any region in a previous year	% seen in any region in a previous year
Northern California	15	6	3	1	7	47
Oregon coast	18	14	0	8	8	44
Grays Harbor and S Washington	7	7	3	0	3	43
N Washington coast	21	19	17	17	17	81
US Strait of Juan de Fuca	15	12	2	6	5	33
Northern Puget Sound	6	4	4	0	4	67
Southern Puget Sound	4	2	0	0	0	0
Boundary Bay	3	0	0	0	0	0
S Vancouver I.	61	60	21	49	45	74
Central Vancouver I.	57	55	20	43	41	72
N of Vancouver I., BC	22	18	10	14	22	100
SE Alaska	4	0	0	0	1	25
All areas	155	119		57	86	55

Table 4a
Matrix of matches between region within 1998. **Bold** numbers along the diagonal show number of animals resighted within the same area.

Region	n	Region									
		CA	OR	GH+	NWA	SJF	PS/BB	SVI	CBC	NBC	SEAK
Northern California	15	5									
Oregon coast	18		11								
Grays Harbor and S Washington	7			7							
N Washington coast	21		1		8						
US Strait of Juan de Fuca	15				1	11					
Puget Sound/Boundary Bay	13						6				
S Vancouver I.	61	1	6		17	6		54			
Central Vancouver I.	57		6		8	3		33	50		
N of Vancouver I., BC	22				1			7	9	16	
SE Alaska	4										0

Table 4b
Matrix of matches for whales sighted in 1998 and other years between regions. Diagonal (**bold**) shows number of whales seen both in 1998 and a previous year in the same region. Columns reflect region seen prior to 1998 and rows show region seen in 1998.

Region sighted in 1998	n for 1998	Region sighted prior to 1998									
		CA	OR	GH+	NWA	SJF	PS/BB	SVI	CBC	NBC	SEAK
Northern California	15	3		2	1	2					
Oregon coast	18		0	2	6	1		3	2	1	
Grays Harbor and S Washington	7			3	1						
N Washington coast	21				16	9		10	6	5	
US Strait of Juan de Fuca	16					2		4	5	4	
Puget Sound/Boundary Bay	13						4	1			
S Vancouver I.	61			1	25	16		21	20	20	
Central Vancouver I.	57	1		3	17	8		10	20	19	
N of Vancouver I., BC	22				2	1		2	3	21	
SE Alaska	4				1	1					0

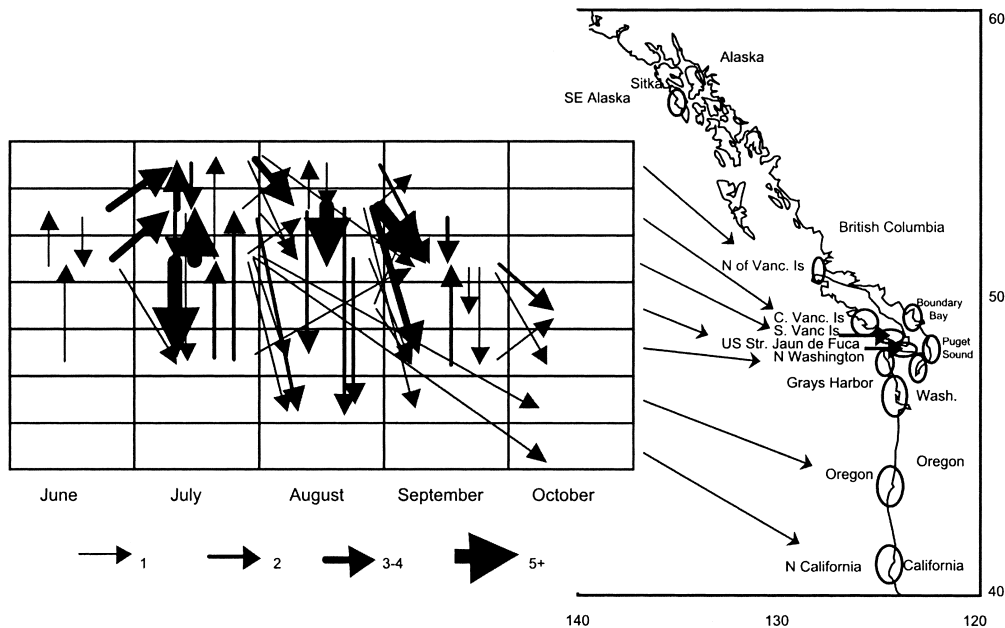


Fig. 2. Movements of gray whales among locations in 1998. Size of arrow indicates number of transits. Movements within a month are shown as vertical lines and movements across months are on diagonals.

northern California. Identifications were primarily made late in the season off Oregon (August) and California (October).

Distance and travel speed were also examined for the 117 whales that were seen on more than one day (Fig. 3). Total distances between resighting positions for individual whales ranged from < 1 to 526 n.miles (great-circle route). The distance a whale was documented travelling through the season averaged 110 n.miles (SD = 137) and was generally directly related to the number of times and span of time over which it was seen. The majority of travel speeds were well under 1 n.mile per hour as would be expected for feeding whales and because the data underestimate the true distance covered (and therefore the speed). Some whales remained in the same area for long periods; for example, ID# 231 was seen 30 times over a 136-day period (23 May to 6 October 1998) off southern Vancouver Island. It accumulated a total distance travelled of only 74 n.miles. The most rapid movement was for an animal (ID# 295) seen seven times from 10-25 August but which moved from central Vancouver Island to Oregon in that period (308 n.miles in less than 10 days). For the eight whales documented moving over 400 n.miles, one transited in one direction from

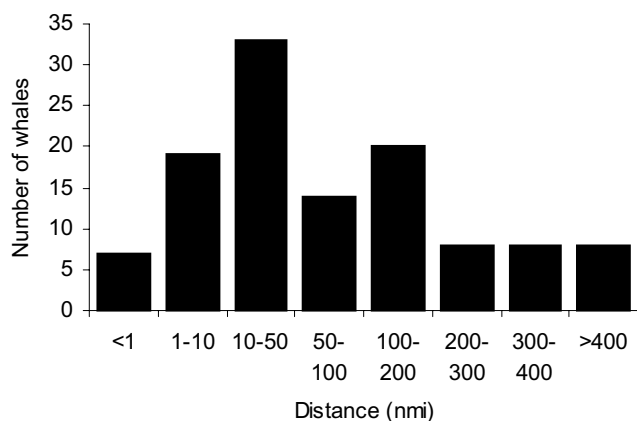


Fig. 3. Distribution of minimum distance whales travelled for 116 gray whales identified multiple times in 1998.

Vancouver Island to California, while the remaining seven made multiple transits in different directions among locations.

Inter-year resightings

Most of the whales photographed in 1998 had been identified in previous years (Tables 3 and 4b). At least 86 (55%) of the whales identified had been previously identified. This number is a minimum because the matches to past years come from comparison of all 155 of the whales identified in 1998 to the historical catalogue maintained by Cascadia Research of whales primarily seen off Washington. There were also matches to previous years identified by several of the collaborating research groups but these were confined to comparisons of whales identified in the same area (the full 155 whales were not compared to the historical catalogues of the other collaborating research groups). Such a comparison would yield additional documentation of resightings of whales in previous years.

Inter-year resightings were highest for whales identified off northern Washington and the three regions of British Columbia from southern Vancouver Island to north of Vancouver Island. In these areas, from 72-100% of the whales seen in each region had been identified in a previous year. These areas are the regions with the heaviest consistent survey effort in past years.

For some areas, such as Oregon and California, there were few identification photographs available from previous years so inter-year resightings were primarily animals that had been seen in other regions in past years. For Oregon, where no identification photographs were available previously, 8 of 18 (44%) whales identified in 1998 had been seen in six other regions from Grays Harbor to northern British Columbia in the previous years (Table 4b). Whales identified off California in 1998 had been seen previously in the Grays Harbor area, the northern Washington coast and the Strait of Juan de Fuca. Three of the whales identified off California were also seen in the only past sample available: a collection of 13 whales identified in November 1991 in the same location they were photographed in 1998 (off Point St George).

Whales identified in 1998 in southern Puget Sound and Boundary Bay had not been seen in a previous year in any region. This finding from southern Puget Sound is consistent with observations from past years; the presence of gray whales in this area is highly variable each year and whales have not been identified previously (Calambokidis *et al.*, 1994). This is different, however, for whales seen in northern Puget Sound, where four of six whales identified were known from sightings in past years. All four of these whales had been identified multiple times since 1990 or 1991. Whales seen in northern Puget Sound generally have been seen from March through May and then move to other unknown areas.

During 1998, whales that had been identified in previous years were seen more times (mean of 10.6 versus 4.7, $t = 4.73, p < 0.001$) over a longer period of time (61 versus 21 days, $t = 6.32, p < 0.001$) (starting earlier and extending later) than whales that had not been identified in previous years (Table 5). This was partly a function of the lower proportion of whales known from previous years in areas like California, Oregon and Puget Sound where resightings within 1998 were less common. Even with the elimination of this regional bias, however, this general trend remained

within the three best-sampled regions (northern Washington and southern and central Vancouver Island).

Although only four whales were identified in southeastern Alaska in 1998 (and none previously), one of these was seen in past years off Washington. Although it was not seen elsewhere in 1998, it had been sighted 18 times in five of the previous six years off both the Washington outer coast and in the Strait of Juan de Fuca. Despite the small sample size, the movement of this whale suggests either the range of this feeding aggregation extends farther north than the primary effort of this study, or that there are other feeding aggregations with some interchange among them.

Seasonal patterns in resighting rates

Whales were identified from 12 March to 19 November 1998 and whales identified early and late in the season included animals seen over extended periods in 1998 and in previous years. There were, however, seasonal differences in the resighting rates of animals in 1998 (Table 6). Less than 50% of whales identified early (March and April) and late (November) in 1998 were known from previous years compared to 57% to 81% for those seen in previous years for May to October (Table 6). These whales were

Table 5

Summary of sighting rates and parameters for gray whales identified in 1998 for whales identified in previous years and whales not identified in previous years.

Times seen by region	All whales			Seen previous years			Not seen prev. years		
	<i>n</i>	Ave	SD	<i>n</i>	Ave	SD	<i>n</i>	Ave	SD
Northern California	15	1.8	1.3	7	1.9	1.6	8	1.8	1.2
Oregon coast	18	2.6	2.4	8	2.1	2.1	10	3.0	2.6
Grays Harbor and S Washington	7	8.3	3.9	3	6.0	4.0	4	10.0	3.4
N Washington coast	21	2.2	2.5	17	2.3	2.7	4	1.8	1.0
US Strait of Juan de Fuca	15	2.3	1.8	5	1.4	0.5	10	2.8	2.0
Northern Puget Sound	6	4.5	2.8	4	4.8	2.6	2	4.0	4.2
Southern Puget Sound	4	1.5	0.6	0			4	1.5	0.6
Boundary Bay	3	1.0	0.0	0			3	1.0	0.0
S Vancouver I.	61	8.0	7.3	45	8.8	7.3	16	5.6	6.9
Central Vancouver I.	57	7.0	7.0	41	7.4	6.4	16	6.1	8.6
N of Vancouver I., BC	22	4.5	4.6	22	4.5	4.6	0		
SE Alaska	4	1.0	0.0	1	1.0		3	1.0	0.0
All areas	155	8.0	8.3	86	10.6	9.0	69	4.7	6.1
Number of regions seen	155	1.5	0.8	86	1.8	0.8	69	1.2	0.4
First date seen (SD in days)	155	13 Jul.	61.4	86	29 Jun.	47.7	69	30 Jul.	71.7
Last date seen (SD in days)	155	24 Aug.	57.9	86	28 Aug.	49.2	69	19 Aug.	67.3
Tenure (minimum days)	155	42.8	44.0	86	60.6	45.9	69	20.6	29.2

Table 6

Summary of identifications and resighting rates of gray whales in 1998 in relation to season.

Season	Unique IDs	No. seen in more than one month/season in 1998	% seen in more than one season in 1998	No. known from a previous year	% known from a previous year
By month					
March	11	8	73	5	45
April	14	9	64	6	43
May	10	9	90	6	60
June	54	54	100	44	81
July	89	80	90	62	70
August	83	69	83	60	72
September	43	41	95	35	81
October	37	21	57	21	57
November	14	5	36	3	21
By season					
Spring (Mar. to May)	25	7	28	13	52
Summer (Jun. to Aug.)	107	45	42	72	67
Fall (Sep. to Nov.)	74	44	59	46	62
All seasons	155	45	29	86	55

disproportionately sampled in Grays Harbor and in Puget Sound so this could partly be the result of regional differences. It also likely reflects the increased probability of sampling migrating whales closer to the time of the migration past the Pacific northwest.

Geographical recruitment

Although it appears that many whales consistently spend most of the feeding season in Pacific northwest waters, it is not known how they are recruited into this group. This is a critical question for evaluating how exploitation would impact this group (Quan, 2000). Some of the sightings in 1998 provide insight into one possible mechanism for the means by which animals adopt this alternate feeding area.

To examine the role that maternally-directed site fidelity plays in whales feeding in the Pacific northwest, some of the sighting history of identified cows and calves was examined. Although females with calves were sighted infrequently, three of the whales sighted in 1997 or 1998 were known reproducing females, plus one was a returning calf. One whale identified off Washington and British Columbia (ID# 43) has been seen in many years since 1984, including every year from 1992-1998. It was documented with a calf in July 1994 (ID# 107) and the calf was seen independently off Washington in three following years, 1995, 1997 and 1998. In the two other cases (ID# 67 and ID# 105), adult females known from multiple years (between 1992 and 1998) had a calf one year (1994 or 1995) that has not been resighted. In at least one of these two cases, the calf photograph was of marginal quality and there is a chance it would not have been recognised even if it had returned.

Estimation of abundance

The sample from 1998 provides a minimum estimate of the total number of whales feeding in summer months from northern California to southeastern Alaska. Although a total of 155 whales were identified, only 137 of these were seen after 1 June, outside the timing of the northern migration (Table 7). Mark-recapture estimates using annual samples from 1998 and either 1996 or 1997 yielded estimates of 181 and 179, respectively (Table 7).

Table 7

Petersen capture-recapture estimates for gray whales identified between June and November 1998 in the Pacific Northwest. See text for explanation of violations of assumptions and biases.

Sample 1		Sample 2		Match	Est.	CV
Year	n	Year	n			
1997	29	1998	137	22	179	0.09
1996	24	1998	137	18	181	0.10

DISCUSSION

While the presence of gray whales feeding during summer months in the Pacific northwest has been reported, there has been only limited research on the abundance and range of movements of these animals. Darling (1984) reported resightings of whales off Vancouver Island over an eight-year period. He documented movements of animals between different areas of up to 80km in the same season and 150km between seasons and estimated that the Vancouver Island area was occupied by 35-50 whales each summer. There were gaps, however, in the sighting histories of these whales, with some individuals not identified in the study area for several years.

This study shows that these whales inhabit a broad region during the spring, summer and autumn extending from at least northern California to southeastern Alaska. Within this range, gray whales can move widely both within and between years. The use of this broad area by these whales provides one explanation for why many of these individuals would not be seen in specific areas in some years. Even with the broad field effort reported here, only relatively small portions of the potential areas of use by these animals are being searched (Fig. 1). The interval of three months between sightings of one individual during which it moved from northern Vancouver Island to California without being sighted in intermediate areas of British Columbia, Washington and Oregon, demonstrates the limited survey coverage. Animals not seen in a particular year could inhabit neighbouring areas where there was no research coverage.

This sample provides both a minimum estimate of abundance based on the number of identifications and an estimate of total abundance using mark-recapture. The estimates using the Petersen mark-recapture method require several assumptions (e.g. Hammond, 1986) that are not totally satisfied by the current sampling.

1. The population is closed

There would have been some natality and mortality between annual samples, although this should be small. There also may be emigration or immigration of animals with the overall 'population' of gray whales.

2. All animals have an equal probability of capture in at least one of the samples

The 1998 sample is the most complete sample obtained and covers a broad geographic area. Even in 1998, however, effort was not systematic and some areas were covered far more thoroughly than others; there was no effort in some portions of the known range of these animals.

3. The two samples are independent of each other such that animals caught or not caught in one sample both have equal probability of being caught in the other sample

The 1996 and 1997 samples are clearly geographically biased and are based on identifications made in a relatively small area (northern Washington, Strait of Juan de Fuca and southern Vancouver Island). Since there is also some bias in the 1998 sample and animals do not appear to redistribute randomly, this would create heterogeneity of capture probabilities.

4. All matches, if present, are found and there are no false matches

There is little probability of false matches because only matches based on photographs showing multiple markings and verified by a second observer were used. Some matches could have been missed although this was kept to a low number by only including good quality photographs and requiring all comparisons to be made by two matchers.

Violations of assumption No. 1 and the probable violation of No. 4 (missed matches) would both bias the estimate upward while the violations of No. 2 and No. 3 would bias the estimate downward. Since violations of No. 1 and No. 4 are likely small, it is possible that the most significant bias would be a downward one caused by the unequal sampling. This would mean the estimates are likely underestimates. Multiple-year samples that more completely and evenly sample the range of this feeding aggregation are needed to refine the estimate.

The gray whales in this feeding aggregation are a relatively small proportion of the overall gray whale population. The total gray whale population was estimated at 26,365 (95% CI 21,800-32,400) in 1997/98 based on censuses conducted on the southbound migration (Hobbs and Rugh, 1999; IWC, 2000). The few hundred animals identified from photographs and based on mark-recapture estimates would make up less than 1% of this population.

The timing of the arrival and departure of the gray whales described in this study coincided with the timing reported for the overall gray whale migration past the Pacific northwest. Initial sightings of these whales that stayed through the season occurred in March, during the peak of the northward migration past the Pacific northwest as determined by Herzing and Mate (1984). Similarly, resightings of whales identified in the summer were made through late November, when the last field effort ended. This is close to the December/January peak of the southward migration (Herzing and Mate, 1984). Since migratory animals could be present through May (Herzing and Mate, 1984), it is hard to distinguish early in the season which whales are migrating through and which would remain in the region. Given this potential overlap, mark-recapture estimates were made excluding animals identified only before 1 June.

Some species of baleen whales show a high degree of maternally-directed site fidelity to specific feeding areas. This has been examined in detail for humpback whales (*Megaptera novaeangliae*) in both the North Pacific and North Atlantic. In the western North Atlantic, humpback whales breed at one primary wintering ground but during the spring disperse to a number of distinct feeding areas in the North Atlantic; interchange among these North Atlantic feeding grounds is limited (IWC, 2002). There are differences in mtDNA among some of these areas (Palsbøll *et al.*, 1997). Similarly, humpback whales in the North Pacific use a number of distinct feeding areas with little interchange among them (Calambokidis *et al.*, 1996; 2001), although interbreeding among these groups does occur to some degree on the wintering grounds (Darling and McSweeney, 1985; Baker *et al.*, 1986; Calambokidis *et al.*, 2001). As in the North Atlantic, maternally directed site fidelity to specific feeding grounds has resulted in pronounced mtDNA differences between these areas (Baker *et al.*, 1990; 1998).

Only limited genetic studies have been done on gray whales. Steeves *et al.* (2001) compared mtDNA from a sample of 16 summer 'resident' whales from Clayoquot Sound, Vancouver Island and compared them to whales from the overall population. They detected no significant differences in mtDNA patterns between these two groups. The lack of a difference could result from one or more of the following: small sample size, too short time frame for isolation to develop detectable differences, or lack of isolation of this group. The power to detect differences genetically could be limited as exemplified by comparisons between eastern and western North Pacific gray whales. Despite the generally accepted separation of these two populations, differences in the proportion mtDNA haplotypes, while significant, do not allow reliable separation of individual animals from these two populations (LeDuc *et al.*, 2002).

The degree to which the gray whales in this feeding aggregation should be managed as a unit separate from the overall gray whale population is unclear. Treating two sub-populations as one when dispersal between them is less than several percent per year could result in depleting one of these sub-populations (Taylor, 1997). There is some

evidence from whaling data to support the existence of sub-populations of baleen whales on a relatively small geographic scale that were depleted and failed to recover (see discussion in IWC, 2001). The gray whales from the Pacific northwest feeding aggregation appear to migrate to Mexico each winter and therefore are part of the larger breeding population of gray whales. Depending on the stability of this group and how they are recruited, they may represent a unit that should be managed separately. While there are some parallels in the site-fidelity to feeding areas between humpback and gray whales there are some clear differences. The low proportion of gray whale calves documented and the possible evidence for a male bias in this group (Steeves *et al.*, 2001) are different from humpback whale feeding aggregations. Additionally, the overall gray whale population migrates past the Pacific northwest *en route* to their main feeding grounds in the Bering and Chukchi Seas. This would provide a mechanism for animals to encounter productive feeding areas on this migration and potentially adopt this alternate feeding area.

The results also indicate that early in the season it could be difficult to determine with certainty which whales were migrating through the region and which were part of the feeding aggregation that remained in the region. This could be an important management concern related to aboriginal takes of whales in the Pacific northwest. During the migration it would be expected that the overwhelming majority of whales in the migratory corridor would be migrating animals based on the large size of the overall gray whale population and the low numbers of whales estimated in the group that stays in the region. However, some of the gray whales identified in this study as early as March (during the gray whale migration) were animals that had been seen in previous years and stayed through the summer and autumn. The most reliable way to select migratory animals would be based on a combination of season (as close as possible to the time of peak migratory passage), location (in the migratory corridor and away from known feeding areas) and behaviour (animals travelling and not milling in an area).

This paper provides new information on the range, movements and abundance of gray whales utilising the waters of California to southeastern Alaska as a feeding area. While this approach does provide valuable new information, a multi-year effort, currently underway, will provide more accurate estimates of inter-year resighting rates and interchange, and abundance estimates.

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Some analyses on the modern whaling catch history of the western North Pacific stock of gray whales (*Eschrichtius robustus*), with special reference to the Ulsan whaling ground¹

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ABSTRACT

This study analysed post-1900 published and unpublished records of gray whales in the western North Pacific. Modern whaling recorded a peak annual catch of 100-200 whales in the 1910s, followed by a rapid decline in the 1920s and 1930s and a continued low level (perhaps 10-20 whales/year) for over 40 years to the 1960s. Catches made during the last phase could have been the major factor suppressing recovery until recently. There are reasons to believe that this gray whale stock breeds in Hainan waters.

KEYWORDS: GRAY WHALE; MIGRATION; WHALING-MODERN

INTRODUCTION

In contrast to the recovery of the eastern North Pacific stock of gray whales (Darling, 1984), no significant sign of recovery has been detected in the 'Asian' or western North Pacific stock (e.g. IWC, 2002). The present study attempts to clarify the catch history of this stock by reviewing published and unpublished records of catches. It also considers some possible reasons for the stock's lack of recovery.

MATERIALS AND METHODS

Published and unpublished records of gray whales taken in Korean and Japanese waters were reviewed, in addition to unpublished records of sightings in the same area.

The major sources of published catch records and the periods covered are as follows: (1) 1890-1903, 1906-1945, 1948 and 1957-1966 Park (1987); (2) 1911-1945 Kasahara (1950); and 1945-1966 Brownell and Chun (1977).

Some data are common between the studies —Park (1987) cited all the statistics (1911-1945) in Kasahara (1950) and the 1957-1966 statistics in Brownell and Chun (1977).

Unpublished catch records were obtained from the private log of an ex-whaling gunner, Mr Toraichiro Emoto, covering the coastal seasons 1923/24-1933/34 and 1941/42-1944/45. They include sightings and catches by species and other information on the operation such as area and whales taken by other vessels. Between 1934 and 1941, Emoto was employed in the Antarctic fleet.

A further source of sightings data was the daily records of whale sightings recorded for the Fisheries Agency of Japan by whaling captains operating in the western North Pacific, East China Sea, Sea of Japan and Okhotsk Sea (Fig. 1). The records cover the periods 1971-1987 (large-type whaling) and 1977-1988 (small-type whaling) and are kept at the National Research Institute of Far Seas Fisheries (Far Seas Fisheries Research Laboratory).

¹ A version of this paper was originally presented as SC/A90/G19.

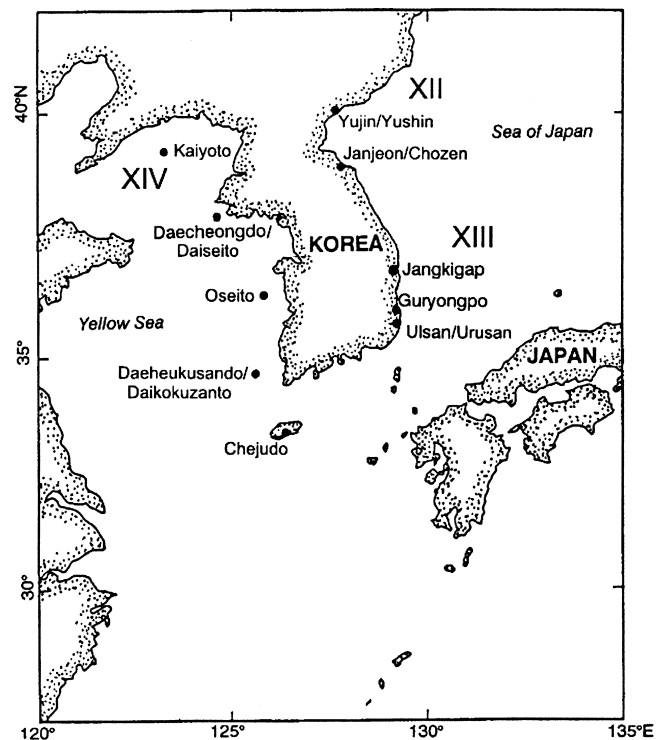


Fig. 1. Land stations (closed circle) used by modern whaling fleets in Korean waters.

Kasahara (1950) grouped the 11 pre-war Korean coastal whaling stations into three areas: (1) Area XII (the northeastern coast bordering the Sea of Japan, the Jangjeon ground of this study); (2) Area XIII (the southeastern coast bordering the Sea of Japan, the Ulsan ground); and (3) Area XIV (the Yellow Sea ground). His classification has been used in the following analysis. Some of the previous studies used Japanese geographical names in Korean waters, but in this study local names have been used as far as possible.

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RESULTS

Catch history

A total of 1,750 gray whales (44 individuals by net whaling) were reported to have been taken from the western North Pacific stock in the 77 years from the start of modern whaling in 1891 to 1966 (Table 1): 1,704 (97.4%) were from the east coast of the Korean peninsula (Jangjeon and Ulsan ground); 3 from the west coast (Yellow Sea ground); and the remaining 43 from elsewhere. It is unclear when the exploitation of gray whales ceased in Asian waters, but it certainly lasted until 1966 (Brownell and Chun, 1977).

Just before modern whaling began off the Korean coast, Japanese net whalers took 16, 15 and 13 gray whales off Pusan (southeastern lower Korean peninsula) in 1890/1891, 1891/1892 and 1898/1899 respectively (Park, 1987). A Russian vessel, from the Pacific Whale Fishing Co., began whaling off the Korean coast in 1890 (Tonnessen and Johnsen, 1982, p.131). This marked the start of modern whaling in Asian waters. The operation continued until February 1904 and the outbreak of the Russo-Japanese war (Akaishi, 1910). Statistics are available for only three seasons in the period 1889/1900-1902/03, i.e. 116, 114 and 96 whales, respectively (Park, 1987). Catches by species are only known for the 1902/03 season, with a take of nine gray whales (about 10% of the total) off Jangjeon (Park, 1987). On the assumption that the Russian whaling fleet took about 100 whales/season and 10% of them were gray whales, the total estimated gray whale take in the 13 seasons 1891/92-1902/03 would be around 130 individuals; these are not included in Table 1, which represents the minimum estimate.

Japanese modern whaling started in Korean waters in February 1900, expanded to wider areas along the Korean and Japanese coasts after the Russo-Japanese war (Akaishi, 1910; Park, 1987) and continued in Korean waters until the end of the Second World War in 1945. Catch statistics by species are available from 1906 onwards. Although no statistics before then give the species composition, at least 37 gray whales are known to have been taken on the Jangjeon ground between 1900-1905 (Park, 1987).

High catches occurred during 1907-1918 with a maximum annual take of 193 whales in 1912. Of the total of 674, 546 (81%) were taken on the Ulsan ground. From 1920, the catch declined annually, but it is clear from the Emoto log that catches continued at a very low level on the Ulsan and Jangjeon grounds until 1945. Although the log does not cover the 1934/35-1940/41 seasons, it is a reasonable assumption that other Japanese vessels will have taken some gray whales in the area. A gray whale was reported in 1942 from a land station on Paramushiro Island in the northern Kuril Islands (Mizue, 1951) which may have originated from the Californian or eastern stock of gray whales.

There are some inconsistencies between the published statistics and the Emoto log. Emoto recorded the take of seven gray whales off the east coast of Korea in 1942/43-1944/45 (Table 1), but none are recorded in the official statistics used by Kasahara (1950) and cited in several studies. Since Emoto's records only covered about half of the total fin whales caught on the Ulsan ground during this period, the total gray whale catch there could have been higher. Additionally, if the operation off northeastern Korea (the Jangjeon ground) is taken into account, the total take of gray whales on the Korean coast could have been higher. During the war years, in the face of threats from enemy submarines, there would have been increased demands on local food sources such as gray whales.

After the Second World War, whaling resumed in the Republic of Korea in 1946 (Park, 1987) and possibly also in the Democratic Peoples Republic of Korea (North Korea). Brownell and Chun (1977) report a total of 67 gray whales taken on the Ulsan ground in the period 1948-1966. Information is not available on catches made in the Democratic Peoples Republic of Korea.

The Peoples Republic of China began modern whaling in 1964 using a catcher boat and there is a recorded catch of at least three gray whales, one each in September 1949, June 1958 and April 1960 (Wang, 1978).

Sightings of gray whales on the Ulsan ground

According to the Emoto log, the catcher boat operated up to 40 n.miles from the coast, mainly for minke and fin whales. There were no gray whale sightings beyond 10 n.miles from the coast.

Emoto recorded 17 sightings (36 individuals) of gray whales on the Ulsan ground during the winter (December and January) in the period 1923-1944. Positions are available for 11 sightings. Most occurred at a depth of $\leq 100\text{m}$ and between Jangkigap and Wejeulgap (Fig. 2). The Emoto log records that the majority frequented the waters off Sogi. School sizes were: 7 singles; one school each of 2 and 3 whales; and 2 schools of 4 animals. There were no records of cow and calf pairs, but it is uncertain whether such schools were either not sighted or not recorded as such.

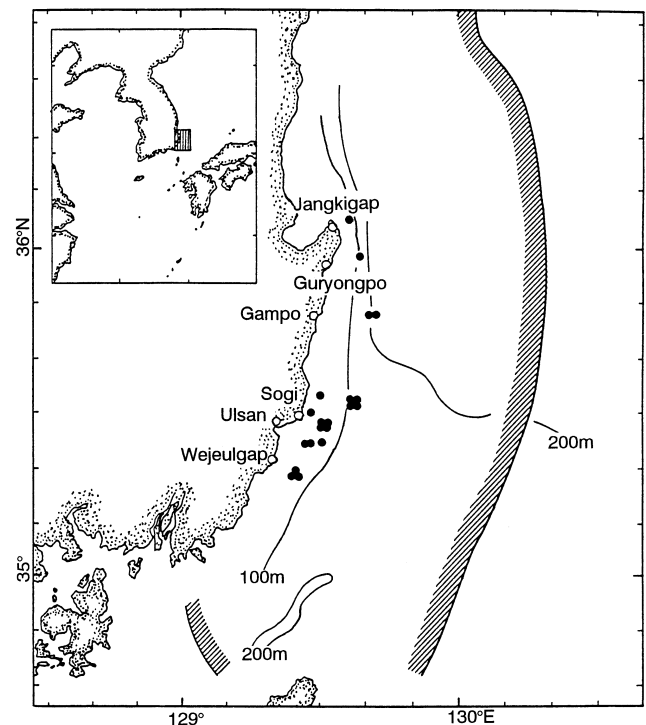


Fig. 2. Sighting positions of gray whales (closed circle) in the Emoto log (1923/1924-1933/1934; 1941/1942-1944/1945) and the ordinary daily rate of operation for fin and minke whales (inside of the shaded area).

Monthly changes in the catch

Table 2 provides monthly catch data from the Ulsan and Jangjeon grounds from published records. These occurred from November-April, with a major peak in December/January and another, smaller peak some three months later, in March/April. Although the discrepancy in magnitude of the two peaks could be due to the general operational pattern of taking fin whales in the Yellow Sea in early spring this could also be interpreted as a reflection of migratory movement south to the breeding ground.

Table 1

Catch history of the Asian stock of gray whales by modern whaling from published records and catch information from the field log by T. Emoto.

Year ¹	Published records ²						Emoto log		
	Ulsan ground	Jangjeon ground	Yellow Sea	Others	Place unknown	Total	Ulsan	Jangjeon	Total min. catch
1890	16 ³	?	?	-	-	16+			16
1891	15 ³	?	?	-	-	15+			15
1892			No data			?			?
1893			No data			?			?
1894			No data			?			?
1895			No data			?			?
1896			No data			?			?
1897			No data			?			?
1898	13 ³	?	?	-	-	13+			13
1899			No data			?			?
1900	?	23+	?	-	-	23+			23
1901	?	?	?	-	-	?			?
1902	?	9+	?	-	5+	14+			14
1903			No data			?			?
1904			No data			?			?
1905			No data			?			?
1906	59	-	-	-	11	70			70
1907	125	-	-	-	-	125			125
1908	26	-	-	-	-	26			26
1909	?	?	?	?	?	?			?
1910	?	?	?	?	?	?			?
1911	106	13	-	2	-	121			121
1912	?	?	?	?	-	193			193
1913	?	?	?	?	-	131			131
1914	109	30	-	16	-	155			155
1915	?	?	?	9	-	139			139
1916	36	41	-	-	-	77			77
1917	53	13	2	-	-	68			68
1918	91	10	2	1	-	104			104
1919	35	11	-	-	-	46			46
1920	51	14	-	10	-	75			75
1921	23	53	-	2	-	78			78
1922	19	19	2	-	-	40			40
1923	4	23	-	-	-	27			27
1924	-	13	-	-	4	17	1	-	18
1925	10	-	-	-	-	10	2	-	10
1926	9	1	-	1	-	11	1	-	11
1927	6	3	-	1	-	10	-	-	10
1928	9	-	-	-	-	9	-	-	9
1929	11	-	1	-	-	12	2	-	12
1930	30	-	-	-	-	30	-	-	30
1931	10	-	-	-	-	10	-	-	10
1932	7	-	-	-	-	7	1	-	7
1933	1	-	-	-	-	1	1	-	1
1934	-	-	-	-	-	-	No data		?
1935	-	-	-	-	-	-	No data		?
1936	-	-	-	-	-	-	No data		?
1937	-	-	-	-	-	-	No data		?
1938	-	-	-	-	-	-	No data		?
1939	-	-	-	-	-	-	No data		?
1940	-	-	-	-	-	-	No data		?
1941	-	-	-	-	-	-	No data		?
1942	-	-	-	1	-	1	1	-	2
1943	-	-	-	-	-	-	1	-	1
1944	-	-	-	-	-	-	-	-	-
1945	-	-	-	-	-	-	-	5	5
1946	-	-	-	-	-	-			-
1947	-	-	-	-	-	-			-
1948	9	-	-	-	-	9			9
1949	4	-	1	-	-	5			5
1950	-	-	-	-	-	-			-
1951	7	-	-	-	-	7			7
1952	1	-	-	-	-	1			1
1953	7	-	-	-	-	7			7
1954	?	-	-	-	-	?			?
1955	?	-	-	-	-	?			?
1956	?	-	-	-	-	?			?

cont...

Table 1 continued.

Year ¹	Published records ²					Emoto log			
	Ulsan ground	Jangjeon ground	Yellow Sea	Others	Place unknown	Total	Ulsan	Jangjeon	Total min. catch
1957	?	-	-	-	-	?			?
1958	7	-	1	-	-	8			8
1959	7	-	-	-	-	7			7
1960	8	-	1	-	-	9			9
1961	3	-	-	-	-	3			3
1962	-	-	-	-	-	-			-
1963	2	-	-	-	-	2			2
1964	3	-	-	-	-	3			3
1965	4	-	-	-	-	4			4
1966	5	-	-	-	-	5			5

¹ Calendar year except for 1900 and 1902 indicating 1900/01 and 1902/03 seasons respectively. ² 1890-1908, 1948 Park, 1987; 1911-45, Kasahara, 1950; 1946-66, Brownell and Chun, 1977. ³ Catch by net whaling.

Table 2

Monthly changes in the catch of gray whales in the Ulsan and Jangjeon whaling grounds.

Month	Ulsan ground			Jangjeon ground		
	1906-1908 ¹	1910-33 ²	1948 ¹	1958-66 ¹	1910-33 ¹	1945 ³
Nov.	3 (2, 1)	9	-	-	2	-
Dec.	112 (53, 59)	209	-	12	61	-
Jan.	90 (19, 71)	125	6	13	3	3
Feb.	1 (0, 1)	-	-	9	1	-
Mar.	4 (1, 3)	5	-	-	12	-
Apr.	- (-, -)	2	-	4	35	-
May	- (-, -)	-	-	1	13	2

¹ Park, 1987; numbers in parenthesis are catches of males and females respectively. ² Kasahara, 1950. ³ Emoto log.

In contrast to the Ulsan ground, the Jangjeon ground recorded two distinct peaks in December and April (about four months apart) and the discrepancy in magnitude of the two peaks is less distinct. The greater time interval on the northern ground (Jangjeon) reflects the difference in timing of the gray whale migration.

Post-war records of gray whales in the northwestern North Pacific

Positions of gray and right whale sightings from Japanese catcher boats are given in Fig. 3. Japanese small-type whaling vessels operated from April-September usually within 60 n.miles of the coast; whale sightings were reported for the seasons 1977-88. Some right whales but no gray whales were recorded by those operations.

Japanese large-type whaling vessels usually operated within 300 n.miles from the coast and reported sightings of whales throughout May-March in the years 1971-87. Records included 'one like gray whale' at 34°31'N, 145°43'E (about 250 n.miles from the nearest coast). The record appears in the Japanese progress report to the International Whaling Commission (IWC) (Anon., 1981) as 'a gray whale'; however it is ignored here as the species identification may be incorrect. The large-type whalers reported nine sightings of right whales, concentrated off Sakhalin, mostly in 1974, suggesting that gray whales wintered much further to the south of the Korean peninsula possibly for breeding.

In addition to the above, there have been five sporadic records (Fig. 3) of gray whales on the Pacific coast of Japan during the period 1968-90 (one whale sighted off the Kii Peninsula; *ca.* 33°30'N-135°30'E) in June *ca.* 1959

(Nishiwaki and Kasuya, 1970); one taken off the Kii Peninsula, February 1968 (Nishiwaki and Kasuya, 1970), one sighting in Ise Bay (34°30'N-136°E), March-April 1982 (Furuta, 1984); one sighting off the Kii Peninsula (*ca.* 33°30'N-136°E), April 1985 (Kasamatsu and Ishikawa, 1990); one stranding on the coast of Sagami Bay (*ca.* 35°N-139°E), February 1990 (Kasamatsu and Ishikawa, 1990).

More recent sightings, of two individuals, were off Izu-Oshima Island (*ca.* 34°30'N-139°30'E) in April 1993 (K. Nakamura and A. Mochizuki, pers. comm.). One animal was stranded at Suttu Town (*ca.* 43°N-140°E), Hokkaido (Kato and Ishikawa, in prep.).

Information on recent sightings of this species in the waters of the Russian Federation is detailed in Weller *et al.* (1999). One juvenile was sighted off the Pacific coast of Kochi, southwest Japan (*ca.* 33°N, 133°E; Kato and Tokuhiko, 1997).

DISCUSSION

The minimum total take of gray whales by modern whaling from the Asian stock since 1891 is estimated to be 1,750 individuals, including 44 caught in net whaling in the 1890s. However, taking into account species uncertainties in the Russian records (100-200 whales) and possible under-recording during the Second World War (10 or more), a better estimate would be between 1,800 and 2,000 individuals. The rapid annual decline to 10-20 whales/season following the peak catches of 100-200 individuals/year at the turn of the century, probably reflected a decline in stock size.

Although it has generally been believed that the catch of gray whales ceased from 1933-1945 (Kasahara, 1950; Mizue, 1951; Omura, 1988), small scale exploitation continued during that period until the mid 1960s. Low level exploitation after World War II has already been documented (Brownell and Chun, 1977). Thus, this stock of gray whales was the focus of low level, but presumably significant, catches for over 60 years following earlier high catches and rapid decline; this may explain the apparent lack of recovery of this stock (and see Weller *et al.*, 2002).

Analysis of available data has identified two distinctive migration peaks along the east coast of the Korean peninsula. These peaks uphold the probability of a breeding area to the south of the Korean peninsula, the first peak in December/January due to southbound migration for winter breeding and the later March/April peak accounting for northbound migration for summer feeding. The waters

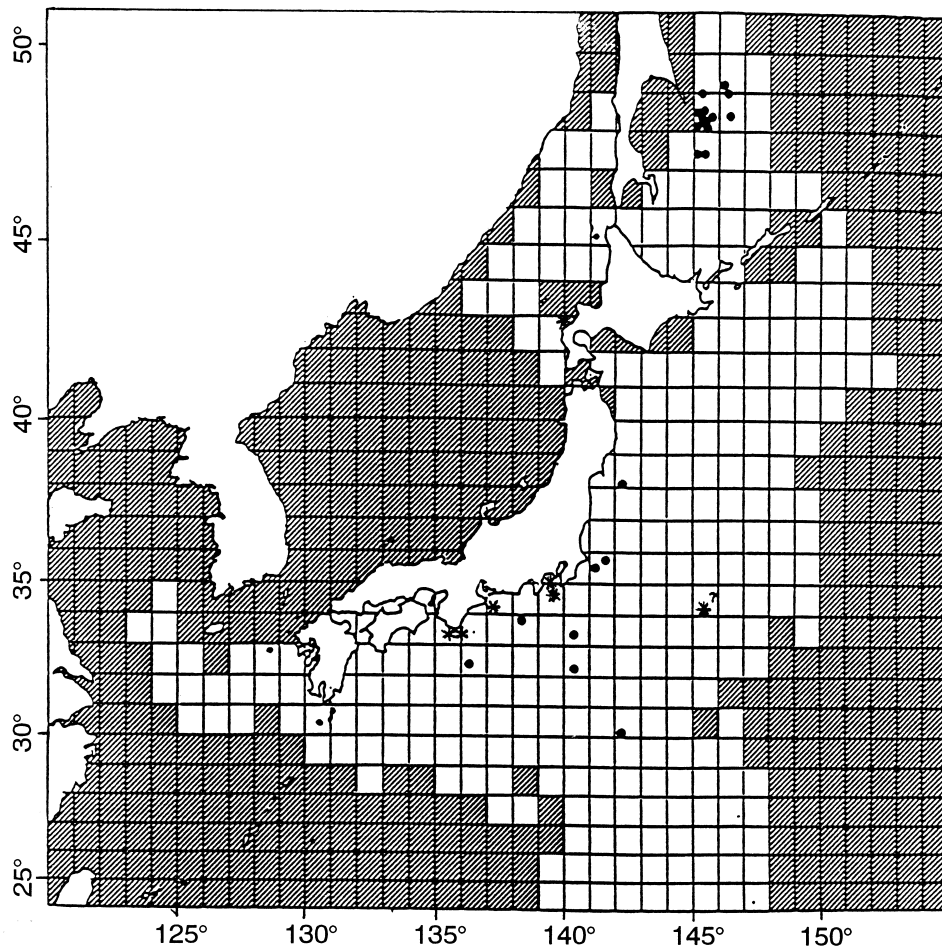


Fig. 3. Position of sightings of gray and right whales reported by Japanese coastal whaling catcher boats and some additional records of gray whales (for details see text). Species key: closed circle = right whale; star = gray whale.

around Hainan Dao island (ca. 20°N, 100°E) were considered by Brownell and Chun (Brownell and Chun, 1977) as the most probable breeding site for the western stock of gray whales. Comparing migration times to those of the eastern stock, the four-month period between southbound and northbound migration for the western stock upholds the possibility of Hainan Dao Island as the southern destination for the migrating whales.

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A note on observations of gray whales in the southern Chukchi and northern Bering Seas, August-November, 1980-89

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ABSTRACT

A total of 176 sightings of 488 gray whales (*Eschrichtius robustus*) were made during 85.6 hours of aerial surveys in the southern Chukchi Sea and northern Bering Sea, east of the International Date Line, from August to early November 1980-1989. Surveys were flown infrequently and effort varied considerably between years and geographic areas. Gray whales were sighted in all areas where surveys were flown, with the exceptions of Kotzebue Sound and Norton Sound. Abundance indices of whales per unit effort (WPUE) in the northern Bering Sea were higher than those in the southern Chukchi Sea during every month except September, when survey coverage was inadequate for abundance calculations, indicating comparatively higher overall use of that area or suggesting the onset of the southbound migration. Most gray whales were feeding (57%, $n = 276$). Incidental sightings of gray whales observed in and near the study area by other researchers were reviewed to better assess gray whale activity and migration patterns.

KEYWORDS: GRAY WHALES; SURVEYS-AERIAL; BERING SEA; NORTH PACIFIC; DISTRIBUTION; MIGRATION

INTRODUCTION

The distribution and migration of the California-Chukotka stock of gray whales is well-documented for most of its range (Swartz, 1986). However, information is still limited for some regions, including the northernmost summering areas in Alaskan waters. Distribution, migration timing and observed behaviours have been described for gray whales in the northern Bering and eastern Chukchi Seas in the summer (Moore and Ljungblad, 1984; Moore *et al.*, 1986b; Würsig *et al.*, 1986), the northeastern Chukchi Sea in the autumn (Moore *et al.*, 1986a; Clarke *et al.*, 1989) and the eastern Alaskan Beaufort Sea in the autumn (Rugh and Fraker, 1981; Würsig *et al.*, 1983). These reports are augmented by reviews of opportunistic sightings in Alaskan waters (Maher, 1980; Marquette and Braham, 1982; Braham, 1984). However, specific information on gray whales in the southern Chukchi Sea and northern Bering Sea east of the International Date Line (IDL) between late summer and autumn is particularly scarce. Aerial surveys have occasionally been conducted in this area since 1980 as one component of a larger survey effort for endangered whales in the Beaufort, Chukchi and Bering Seas. This paper summarises the sightings of gray whales reported during these surveys and reviews other relevant information from the literature.

METHODS

The study area included coastal and offshore regions of the southern Chukchi Sea and the northern Bering Sea (63° to 69°N) east of the IDL (Fig. 1) which was divided into survey blocks. The area approximates the boundaries of the Hope and Norton Basin Outer Continental Shelf (OCS) Planning Areas, as designated by the US Department of the Interior, Minerals Management Service (MMS) for decision-making regarding offshore oil and gas activities. Two types of aerial surveys were flown: transect surveys along randomly selected east-west transect lines in survey blocks; and search surveys while transiting to offshore survey blocks (Moore *et*

al., 1986b). Surveys were flown in a Grumman Turbo Goose model G21G at 152-458m altitude and speeds of 222-296km per hour.

Data routinely collected at each sighting included aircraft altitude, time, latitude, longitude, ice conditions, sea state, visibility, species, number of animals at the surface, number of visible calves, orientation of individual(s) at first sighting, behaviour and inclinometer angle. Whale behaviour classifications included swimming, diving, resting, milling, feeding, mating, cow-calf interaction and displaying. Survey effort and gray whale distribution were analysed for each month. Temporal (by month) and spatial (by survey block) abundance were derived as number of whales per survey hour (WPUE, whales per unit effort).

RESULTS

A total of 85.6 survey hours was flown, with 47.3 hours in the southern Chukchi Sea and 38.3 hours in the northern Bering Sea between August and November 1980-1989¹ (Fig. 2; Table 1). Survey effort was not consistent between years (Fig. 3): there were no surveys in the study area in 1982, 1984, 1985 or 1988. Flight effort in September was limited to the northernmost section of the study area near Point Hope, while survey coverage was most widespread in October. Total flight effort per month varied from 6.4hrs in September to 34.9hrs in October, with 70% (50.9hrs) of total survey effort in October and November.

There were 176 sightings of 488 gray whales in the study area (Fig. 4; Table 2). Gray whales were sighted in all areas where surveys were flown with the exception of Kotzebue Sound (blocks 30 and 31) and Norton Sound (block 29). In August, whales were seen just south of St Lawrence Island and in offshore waters between the Bering Strait and St Lawrence Island, with a single sighting of three animals north of Bering Strait in the southern Chukchi Sea. In September, gray whales were nearshore south of Point Hope

¹ Limited aerial survey effort continued in the study area in November 1990 and 1991 (Clarke and Moore, 1993); no gray whales were seen and the survey effort is not incorporated here.

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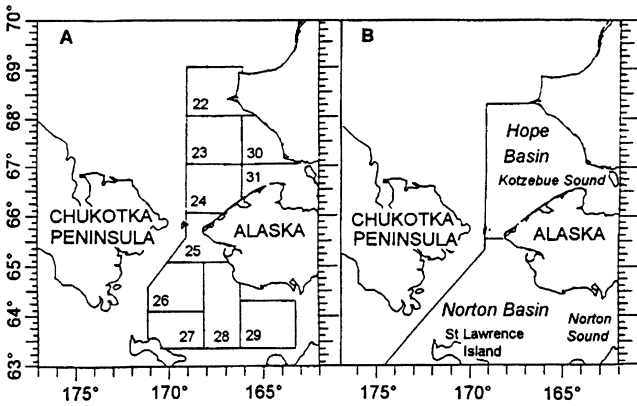


Fig. 1. Study area depicting survey blocks (A) and Hope Basin and Norton Basin OCS Planning Areas (B).

peninsula. The October sightings were offshore in the south-central Chukchi Sea and north-central Bering Sea, with scattered sightings along the coast. In November, gray whales were seen west of St Lawrence Island and in offshore areas south of Bering Strait, with one whale north of Bering Strait.

Monthly abundance indices (WPUE) for the southern Chukchi Sea (Table 1) were highest in October (5.3) and September (5.0) and negligible in August and November (<0.5). WPUE in the southern Chukchi Sea was highest in block 23 (12.3) in October and block 22 (6.4) in September. In the northern Bering Sea, WPUE values were highest in October (11.3) and November (10.8) and considerably lower in August (3.0). The highest WPUE value was in block 26 in November (32.1). Comparing the two regions, WPUE was higher in the northern Bering Sea during every month except September, when survey coverage (0.8 hours) was inadequate. The indices were probably influenced by the sporadic survey effort, but may indicate comparatively greater use of the northern Bering Sea region or be an indicator of the onset of the autumn southbound migration from the Chukchi Sea.

The majority of whales seen were feeding (57%, $n=276$), as evidenced by mud streaming from the whale's mouth or by the presence of conspicuous mud plumes, which are large billows of sediment brought to the surface by bottom feeding

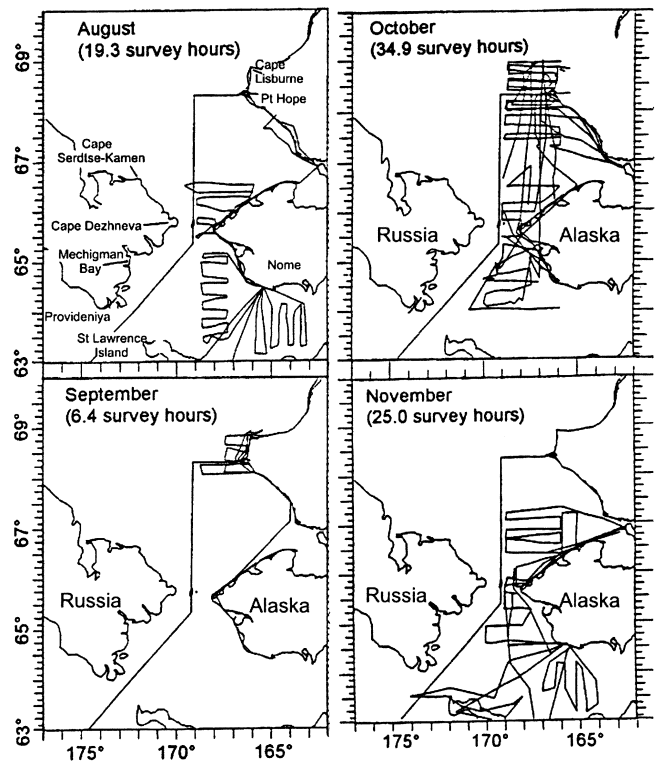


Fig. 2. Monthly composite flight tracks, 1980-89.

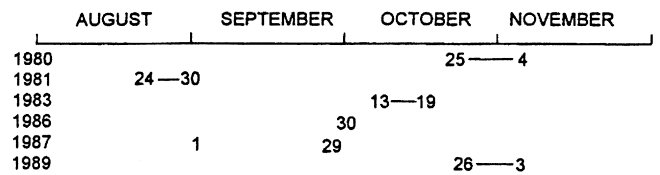


Fig. 3. Breakdown of monthly survey effort, 1980-89, showing dates on which flights occurred.

whales. For a significant proportion (25%, $n=124$) of whales, no behaviour was recorded. Other behaviour observed included swimming (16%, $n=78$), diving (1%, $n=7$) and displaying (1%, $n=3$). Feeding whales often changed swim direction while at the surface and generally

Table 1

Relative abundance of gray whales by survey block, August-November 1980-89 (does not include 12 whales seen in unblocked areas in August 1981 and November 1980). WPUE = whales per unit of effort (i.e. per hour).

Survey block	August			September			October			November			Total		
	Hrs	No.	WPU	Hrs	No.	WPUE	Hrs	No.	WPU	Hrs	No.	WPU	Hrs	No.	WPUE
Southern Chukchi															
22	0.5	0	0	4.4	28	6.4	11.1	61	5.5	0	-	-	16.0	89	5.6
23	0	-	-	0	-	-	5.3	65	12.3	1.1	0	0	6.4	65	10.2
24	2.4	3	1.3	0.2	0	0	4.2	2	0.5	4.8	1	0.2	11.6	6	0.5
30	1.5	0	0	0.7	0	0	2.9	0	0	0.8	0	0	5.9	0	0
31	2.9	0	0	0.3	0	0	0.5	0	0	3.7	0	0	7.4	0	0
Total	7.3	3	0.4	5.6	28	5.0	24.0	128	5.3	10.4	1	0.1	47.3	160	3.4
Northern Bering															
25	3.6	12	3.3	0.7	0	0	4.0	38	9.5	3.5	44	12.6	11.8	94	8.0
26	0.9	17	18.9	0	-	-	4.9	83	16.9	3.3	106	32.1	9.1	206	22.6
27	0.6	1	1.7	0	-	-	0	-	-	1.3	3	2.3	1.9	4	2.1
28	3.5	6	1.7	0.1	0	0	2.0	2	1.0	4.1	4	1.0	9.7	12	1.2
29	3.4	0	0	0	-	-	0	-	-	2.4	0	0	5.8	0	0
Total	12.0	36	3.0	0.8	0	0	10.9	123	11.3	14.6	157	10.8	38.3	316	8.3

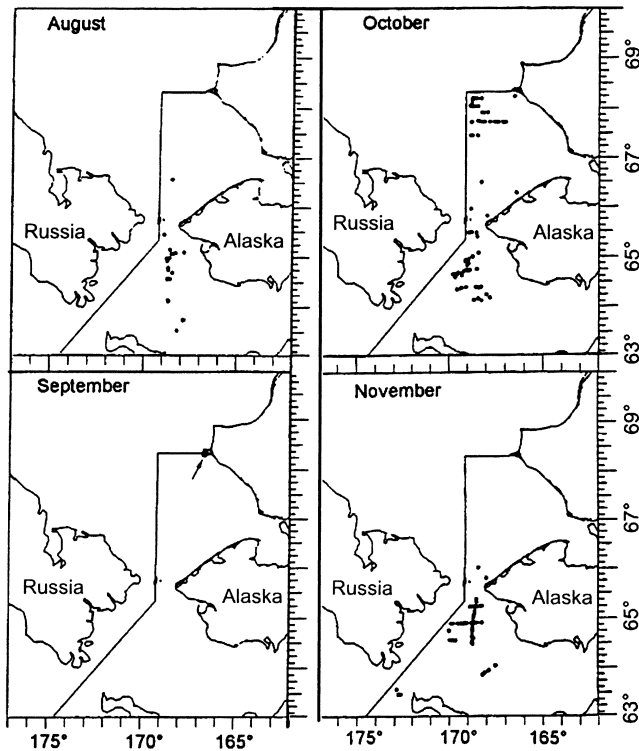


Fig. 4. Distribution scattergram depicting 176 sightings of 488 gray whales, 1980-1989: 28 sightings of 46 whales in August; 6 sightings of 28 whales in September (denoted by arrow); 82 sightings of 251 whales in October; 60 sightings of 163 whales in November. Each symbol represents one sighting of one or more whales. There were two sightings in August to the southeast of St. Lawrence Island (ca 63°N, 169°W).

Table 2

Monthly summary of gray whale sightings per number of whales August-November 1980-1989. * = no survey effort during this time period.

Year	August	September	October	November	Total
1980	*	*	44/125	60/163	104/288
1981	28/46	*	*	*	28/46
1983	*	*	3/7	*	3/7
1986	*	0	*	*	0
1987	*	6/28	*	*	6/28
1989	*	*	35/119	*	35/119
Total	28/46	6/28	82/251	60/163	176/488

did not show any concerted movement in any one direction. Therefore, whales seen feeding were not considered to be actively migrating and swim direction analyses excluded feeding whales. Consequently, there were insufficient data on swim direction collected to warrant analysis. One calf was seen in the study area, south of Point Hope in September 1987 (Clarke *et al.*, 1989).

DISCUSSION

Gray whales in the southern Chukchi Sea and northern Bering Sea of Alaska in late summer and early autumn have not been extensively studied for several reasons. The southern Chukchi and northern Bering seas are not important areas of offshore oil exploration and development, a factor greatly influencing the degree of interest and funding available for biological studies in the region. Additionally, unlike bowhead whales (*Balaena mysticetus*) which are actively hunted by Alaskan Eskimos, gray whales make only a minor contribution to native subsistence in a few US

communities (Marquette and Braham, 1982; Krupnik, 1987). Thus, the incentive in the USA to support research on sustainable yields for gray whales is not as great as for bowhead whales. Finally, the California-Chukotka gray whale stock was removed from the Endangered Species List in June 1995 after having recovered to, or bypassed, pre-exploitation size (Breiwick *et al.*, 1988). Gray whales therefore do not receive the same scientific and financial consideration shown to other, more critically endangered, whale populations such as the bowhead whale or the North Atlantic right whale (*Eubalaena glacialis*).

Consequently, most information available concerning gray whales in and adjacent to the study area comes from incidental sightings made during research targeting other species. The data suggest that the southern Chukchi Sea supports relatively high gray whale densities throughout the late summer and autumn. Large gray whale aggregations were described from aerial and shipboard surveys both along the northern coast and offshore of the Chukotka Peninsula (Fig. 5). Soviet researchers conducting aerial surveys in August and October 1973 reported the highest densities of gray whales nearshore north of the Chukotka Peninsula between Cape Dezhneva (East Cape) and ca 175°W. Large aggregations were also located offshore at 68°N, 169°05'W (Zimushko and Ivashin, 1980; Berzin, 1984). Likewise, in late September and early October 1975, aggregations were located offshore north of Cape Serdtse-Kamen and north of Cape Dezhneva. During joint Soviet-American research cruises, large groups of gray whales were seen in October 1979 (>250) and October 1980 (>580) north of Cape Serdtse-Kamen (Berzin, 1984) as well as nearshore along the northern Chukotka coast (Miller *et al.*, 1985). Large aggregations were again reported along the coast and north of the Chukotka Peninsula in August and September 1982, with scattered sightings near Point Hope (Berzin, 1984; Miller *et al.*, 1985). Similarly, Blokhin (2003) counted 1,450 gray whales in a broad area north of the Chukotka Peninsula in August 1986. Joint Japanese-Russian-American oceanographic cruises in September-early October 1992-1994 documented gray whale aggregations north of the Strait and nearshore along the northern Chukotka coast (George, 1992; Moore, 1993). These data, combined with the gray whale sightings reported here in the southern Chukchi Sea in October 1989, indicate that the southern Chukchi Sea is an important gray whale habitat throughout late summer and autumn.

Incidental sightings data for the northern Bering Sea lead to more ambiguous conclusions. Gray whale aggregations are routinely reported along the southern Chukotka coast between Cape Dezhneva and Provideniya in association with Soviet whaling (Fig. 5; Zimushko and Ivashin, 1980; Berzin, 1984; Miller *et al.*, 1986; Blokhin, 2003). Whales were seen there as late as November in 1984 and 1987 (Blokhin, 1990). In addition, Blokhin (1990) noted that large numbers of gray whales occupy Mechigmen Bay (Mechigmenskiy Zaliv) from August to October in some years. Aggregations of gray whales were also reported offshore between St Lawrence Island and Bering Strait in September-October 1975 (Zimushko and Ivashin, 1980) and in November 1980 (Fig. 4), but these waters have rarely been surveyed in the autumn. Additional incidental data include five sightings of an unspecified number of whales near St Lawrence Island in September-October 1958-1981 (Braham, 1984), two gray whales in northwest Norton Sound in September 1982 (Leatherwood *et al.*, 1983) and scattered sightings of a few gray whales north of St Lawrence Island in December 1984 (Kibal'chich *et al.*, 1986). Gray whales were observed

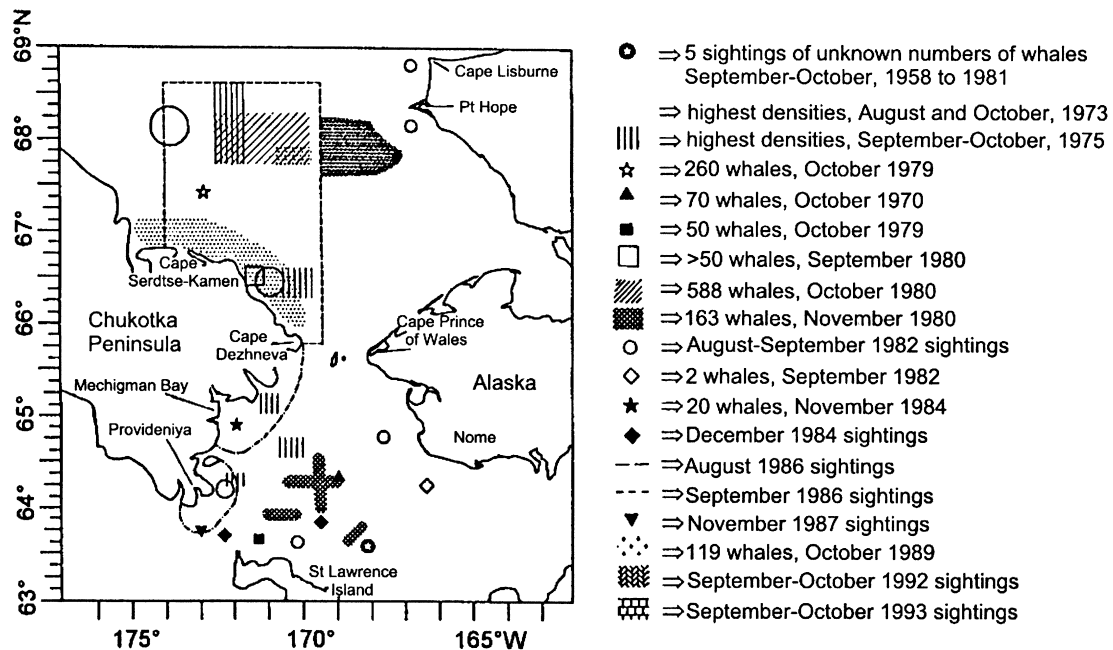


Fig. 5. Gray whale sightings and high density areas in or adjacent to the study area, 1958-93.

during the joint Japanese-Russian-American oceanographic cruises in late September and early October 1992 and early October 1993 south of the Strait (George, 1992; Moore, 1993).

Describing patterns of gray whale abundance and migration based on the available data is difficult owing to the lack of consistent and comparable survey effort, but some trends are worth noting. Gray whales have been seen in the northern Bering Sea as late as November and December (see Figs 4 and 5), by which time others will have reached the coasts of Oregon and California on their southbound migration (Herzing and Mate, 1984; Graham, 1990). The onset of the southbound migration from the southern Chukchi and northern Bering Seas is probably influenced by ice conditions. Rugh (1984) noted that the 1977 southbound migration past Unimak Pass was 10-11 days earlier than that in 1978, when ice conditions were far lighter and the ice front was much further north. Overall, ice front advances could be correlated with differences in median whale migration dates during 1977-9, although year-to-year variations in ice conditions were far greater than in whale migration dates (Rugh, 1984). Likewise, Graham (1990) estimated the peak migration date past San Clemente Island during the 1988/1989 southbound migration (14 January) to be six days earlier than that of the 1986/1987 migration (20 January) and five days later than that of the 1987/1988 migration (9 January); 1986 and 1987 were both considered light ice years, while 1988 was a heavy ice year in the Alaskan Arctic (Moore and Clarke, 1990). Blokhin (1990) also suggested that gray whales are probably present along the coastline of the Russian Far East, including the Chukotka Peninsula, into December, depending on the prevailing ice conditions. Therefore, while ice cover probably influences gray whale distribution and migration timing in the southern Chukchi and northern Bering Seas, the extent of the influence is unknown.

Gray whales return annually to particular regions in the southern Chukchi and northern Bering Seas which are apparently rich feeding grounds for adult whales (Clarke *et al.*, 1989; Blokhin, 2003) and/or weaning areas (Yablokov and Bogoslovskaya, 1984; Moore *et al.*, 1986b). The size

segregation observed off Chukotka may be related to differential prey availability. Stoker (1990) suggests that smaller whales feed on smaller amphipods commonly found inshore, while larger whales feed further offshore on larger amphipods. Estimates of standing benthic stocks in various regions of the northern Bering and Chukchi Seas indicate that gray whales take advantage of those areas where the benthic community biomass is most dense, such as the Chirikov basin south of St Lawrence Island. Areas where gray whales are usually not seen feeding, such as north of St Lawrence Island, are often characterised by benthic communities dominated by species not preferred by gray whales (Stoker, 1990). Blokhin (2003) reported that preliminary hydrobiological results indicated that the area between Cape Serdtse-Kamen and Cape Dezhneva had the highest measured biomass of prey preferred by gray whales (62% of the total measured benthic biomass). This area was where the greatest proportion of whales (57%) was seen. However, it was pointed out that the occurrence of whales did not always coincide with areas of high benthic concentration and it was consequently suggested that gray whales probably graze from area to area. The lack of gray whale sightings in Kotzebue and Norton sounds may be due to the lack of preferred prey in those areas. Such sounds typically contain brackish water, which support prey species ingested by anadromous fishes rather than mysticete whales (Cooney, 1981). Additionally, Frost and Lowry (1988) report that crangonid shrimp, a preferred food for spotted seals and white whales but not gray whales (Nerini, 1984), are abundant in Kotzebue Sound.

The information presented here is of limited significance due to the circumstances under which it was collected, as it does not lend itself to the testing of hypotheses on gray whale abundance, migration patterns and behaviour. There has been no additional dedicated research on gray whales in the northern Bering and southern Chukchi Seas since 1989. Aerial surveys dedicated to determining gray whale distribution and relative abundance in this area were flown for one week in summer 2002 (Moore *et al.*, 2002). Results from that limited effort suggest that the northern Bering Sea may no longer be a primary feeding ground. Information on

gray whales in this area will probably continue to result from incidental sightings by researchers on projects targeting other species or with other primary interests. Despite this, the material presented here provides some additional insights into gray whale natural history in a geographic area that is not well known.

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An evaluation of gray whale (*Eschrichtius robustus*) mortality incidental to fishing operations in British Columbia, Canada¹

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ABSTRACT

Gray whale (*Eschrichtius robustus*) mortality incidental to commercial fishing operations in British Columbia (BC), Canada was evaluated by two methods: a mailed questionnaire survey of all commercial fishing licence holders in the province; and a review of records of incidental catches, strandings and dead floating animals from published and unpublished sources. Of 5,375 surveys sent out, 848 were returned of which 729 could be used (15.8%). Forty-two incidents with gray whales were reported, including three mortalities. From sources other than the questionnaire for the period up to 1989, 41 records of stranded and dead floating gray whales were obtained, of which four were judged to have been killed incidentally in fishing operations. Twenty-six of these animals had not been examined closely, but extrapolation from the 15 detailed records suggests that 27% of the dead gray whales reported in BC die incidentally in fisheries. Collisions with fishing gear are estimated to occur approximately 20 times per year. Mortality occurs in salmon drift gillnet, salmon seine, longline and trap fisheries. There is also one record of an individual entangled and drowned in a herring net pen, as well as an individual entangled in a herring set gillnet. Estimates of annual mortality are approximately two individuals using data obtained from the questionnaire and 2.4 individuals using stranding data. Biases are present for both sampling methods, but the estimated mortality levels are small relative to population size. Subsequent records ($n=40$) for the period 1990–95 were also examined for comparison.

KEYWORDS: GRAY WHALE; NORTH PACIFIC; INCIDENTAL CAPTURE; STRANDINGS

INTRODUCTION

Much information is available on the stock size, population dynamics, reproductive parameters and geographic range of the gray whale, *Eschrichtius robustus*, e.g. IWC (2003). In addition, estimates of mortality from all non-natural sources are needed if sustainable catch limits are to be estimated. For gray whales, directed aboriginal subsistence takes are reported, but the levels of indirect mortality from encounters with commercial fishing gear were for a long time largely unknown.

There are three general methods of studying mortality incidental to fisheries: (1) questioning fishermen; (2) having dedicated observers recording kills on fishing vessels; and (3) examining stranded or entangled individuals (Hall and Donovan, 2002). In British Columbia (BC), Canada, dedicated observers are generally not required in domestic fisheries and little work was done on strandings prior to the late 1980s. Although several studies of gray whales have been undertaken along the BC coast (e.g. Jones *et al.*, 1984; Reeves and Mitchell, 1988; Duffus, 1996; Dunham and Duffus, 2002), none have examined strandings or incidental mortality. In fact, prior to 1987, the only detailed published stranding record was presented in Pike and MacAskie's (1969) comprehensive review of the marine mammals of British Columbia. In Reeves and Mitchell's (1988) review of the status of the gray whale, no mention is made of entanglements in fishing gear in Canadian waters, although entanglements with fishing gear and strandings from elsewhere in their range have been reported by numerous authors (e.g. see Heyning and Dahlheim, In Press). Fisheries-related mortality of other species of cetaceans in Canadian waters has been reported by several authors (see

review by Barlow *et al.*, 1994). However, from an examination of unpublished references (i.e. Goodman, 1984; Canada, 1985) and from work on strandings (Baird *et al.*, 1988; 1991; Stacey *et al.*, 1989; Langelier *et al.*, 1990; Guenther *et al.*, 1995), it is clear that gray whale strandings and incidental catches in BC are more frequent than indicated by the published literature.

This study attempted to estimate the levels of incidental mortality of gray whales in BC using two methods: a mailed questionnaire survey to commercial fishermen; and a review of both published and all available unpublished records of stranded and dead floating gray whales (hereafter these two types of records are referred simply as stranding records). Derivation of estimates using the two different methods also allows examination of the biases involved in using such methods for estimating incidental mortality. Estimates of incidental mortality of gray whales in BC can be combined with such estimates from elsewhere in their range (Heyning and Dahlheim, In Press), for use in better understanding their population dynamics.

METHODS

Questionnaire data, 1989

A single page questionnaire and a pre-paid, pre-addressed return envelope were sent to all commercial fishing licence holders in BC in 1989. A total of 5,375 surveys was mailed to the licensees.

The questionnaire was prefaced with an introductory letter that described the nature of the study. It also noted that gray whale populations were healthy and increasing in order to allay fears that responses, especially those involving whale mortality, would lead to restrictive management measures. In the present analysis, it has been assumed that all questionnaires were completed in good faith. Licence

¹ An earlier version of this paper was submitted to a special meeting on gray whales in 1990.

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holders were requested to return the questionnaire, regardless of whether or not they had any incidents involving gray whales to report. The questionnaire began with an inquiry about whether gray whales had ever been encountered during fishing operations. This was done to encourage responses regardless of whether or not gray whale collisions with gear had occurred. A request for records of all net or gear collision incidents with gray whales over the licence holder's entire fishing career followed. An incident was defined as a whale coming into physical contact with any fishing gear. To increase the total number of records, the time horizon was purposely left unbounded. It was thought that gray whale gear encounters should be relatively immune to the potential bias introduced by poor respondent recollection.

For each reported incident with a gray whale, the whale's status was recorded and classified as either: (1) dead; (2) swam away apparently uninjured — no gear damage sustained; (3) swam away apparently uninjured — gear damage sustained; (4) swam away injured; (5) swam away condition unknown; or (6) unknown.

Further questions referred to the number of years fished and the type of fishing gear. This information was used to stratify the responses and estimate the total mortality. Although in 1989 there were 8,160 licences issued, some vessels were licensed for more than one gear type (Dept. of Fisheries and Oceans, Licence Unit Statistics) and the questionnaire allowed for reporting of multiple gear types. If a licence holder used more than one gear type and the number of years fished for each type was not specified, a value was assigned to each type based on the best information available. Over 2,000 licence holders fished with both salmon drift gillnets and trolling gear. Most fished for all or most of the trolling season and used gillnets for approximately 30% of the gillnet season (S. Beckmann, DFO, Victoria, pers. comm., 1990). As a result, respondents indicating that they fished with both gillnets and troll gear were listed accordingly when assigning number of years fished. Except for shrimp trap gear, other fishing gear types are generally mutually exclusive and therefore the number of fishing years listed were divided equally among the gear types listed. Even though this may not be the case in all situations, seasons for most gear types overlap and individual boats usually only fish one gear type at a time. Any responses that did not include fishing years or gear specification, or where gear type could not be classified according to licence types were excluded from the analysis of the estimated mortality rate. For the purposes of this analysis, the identifications of gray whales were assumed accurate.

Other questions peripheral to the gray whale incidental mortality issue were included specifically to find the extent of gear damage and gather information about mortality of other cetaceans. Data from this portion of the questionnaire have also been used to estimate incidental mortality for small cetaceans along the BC coast (Stacey *et al.*, 1997).

Stranding data

Information on gray whales was collected from three general sources: (1) cetacean stranding and collection records were examined at the Cowan Vertebrate Museum, University of British Columbia (UBC), the Royal British Columbia Museum (RBCM), the Marine Mammal Division, Pacific Biological Station, Department of Fisheries and Oceans, the Simon Fraser University, the University of Victoria and the Vancouver Public Aquarium; (2) records collected since 1987 through the Stranded Whale and Dolphin Program of

BC; and (3) a request for information on gray whale entanglements and strandings that was sent to over 170 institutions, researchers, Universities, charter operations, lighthouse keepers and other individuals that may have been in a position to find or hear of dead gray whales, or who have previously worked in BC on marine mammals. To avoid duplicate reporting of a single stranding, we compared all dates for which animals were reported, examined available photographs and compared lengths, state of decomposition, distance between strandings and sex. All records presented were believed to be legitimate. Records of stranded gray whales were examined for evidence of an encounter with fishing gear, such as lines wrapped around any part of the body or markings on the skin. Where possible, for both published and unpublished records, original field notes were examined for evidence of collision with fishing gear. If the animal had been examined closely by the original observer and no such evidence was found, it was recorded as not having been caught. If the animal had been only superficially examined or was not examined at all and if it was impossible to tell if the whale had been incidentally caught from a study of the field notes, the cause of death was recorded as unknown. The ratio of those animals that had signs of being caught to those that had no evidence of it but were examined closely was then extrapolated to the unknown records.

Subsequent to the above survey, a series of annual reports from the Stranded Whale and Dolphin Program of BC were examined for comparison (Baird *et al.*, 1991; 1994; Guenther *et al.*, 1992; 1993; 1995; Willis *et al.*, 1996) with the earlier results.

RESULTS

Questionnaire data

Of the 5,375 questionnaires sent out, 848 (16%) were returned. Of the 848, 729 were used; the remainder were excluded as they were incomplete. All records were entered into a database. The number of licence holders, the number of survey respondents, the percent reply and the total number of years fished, all according to gear type, are shown in Table 1.

Table 1
Questionnaire response rates by fishing gear type.

Gear type	No. license holders	No. responses per gear type	Percent reply	Total person yrs fished
Seine	548	77	14.1	1,659.5
Gillnet	3,230	399	12.4	5,492.5
Troll	3,232	438	13.6	8,357.0
Shrimp trawl	247	24	9.7	531.0
Groundfish trawl	142	6	4.2	135.0
Shrimp trap	867	30	3.5	342.0
Longline	435	127	29.2	1,396.0
Total	8,701	1,101 ¹	12.7	17,913.0

¹This differs from the total number of questionnaires received (848) because some respondents hold more than one licence. Also, responses not including the number of years fished or with incomplete responses regarding gear types are excluded.

The number of respondents who had encountered gray whales during their fishing operations was 404 (55.4%). Thirty-seven (5.1%) experienced incidents with gray whales with a total of 42 gray whale incidents (Table 2). Of these, three resulted in mortality, one each with salmon seine,

salmon drift gillnet and longline gear. There was only one definite injury reported, in a troll incident, where the respondent noted the whale had 'some scratches'. In the most common end-result of an incident (11 cases e.g. 26.2%) the whale reportedly swam away in an unknown or unspecified condition. There were 12 incidents (28.6%) where no information was given on the outcome of the incident.

Based on the total number of incidents for each gear type and the number of licence holders for 1989, an annual estimate of about 20 collisions with fishing gear (including all possible outcomes) was derived (Table 3). The ratio of known mortalities to the number of gray whales that swam away after an incident (from Table 2) was extrapolated to the number of incidents with unknown outcomes. This estimate was added to the number of known mortalities for an estimated number of mortalities for each gear type (Table 3). From this the estimated annual mortality for each gear type was calculated based on the number of licence holders for 1989. The total estimated annual mortality was approximately two individuals. Of those gear types where mortality occurred, the mortality per total years fished was highest for salmon seine and lowest for salmon drift gillnet (Table 3).

Table 2

Number and type of gray whale incidents (collisions with fishing gear) from questionnaire. Incident types: 1= number incidents; 2 = number mortalities; 3 = number swam away with no gear damage; 4 = number swam away with gear damage; 5 = number swam away injured; 6 = number swam away unknown; 7 = number unknown.

Gear type	Incident types						
	1	2	3	4	5	6	7
Seine	7	1	1	1	0	0	4
Gillnet	19.23 ¹	1	2	6	0	7	3.23 ¹
Troll	13.77 ¹	0	1	3	1	4	4.77 ¹
Shrimp trawl	1	0	1	0	0	0	0
Groundfish trawl	0	0	0	0	0	0	0
Shrimp trap	0	0	0	0	0	0	0
Longline	1	1	0	0	0	0	0
Total	42	3	5	10	1	11	12

¹The numbers listed for total incidents and unknown incidents for gillnets and troll gear are not whole numbers since one incident was reported by the respondent without distinguishing between these two gear types, and was thus divided among them based on the relative proportions typically fished for combination licence holders.

Table 3
Estimated gray whale mortality from questionnaire.

Gear type	Est. no. of mortalities	Mortality per total years fished ¹	Est. no. gear collisions per year ²	Est. mortality per year ²
Seine	3.00	0.0018	2.31	0.99
Gillnet	1.22	0.0002	11.31	0.72
Troll	0	0	5.33	0
Shrimp trawl	0	0	0.46	0
Groundfish trawl	0	0	0	0
Shrimp trap	0	0	0	0
Longline	1.00	0.0007	0.31	0.31
Total	5.22	0.0027	19.72	2.02

¹This measure of catch per unit effort was calculated with the simplifying assumption that all gear types are equivalent for number of hours fished per season and for the quantity of gear in the water.

²Based on the number of licences for 1989.

Stranding data

All records collected prior to 1990 are presented in Table 4, with locations shown in Fig. 1. The dates noted are the earliest dates for each stranding; for many individuals, records from later dates were also available.

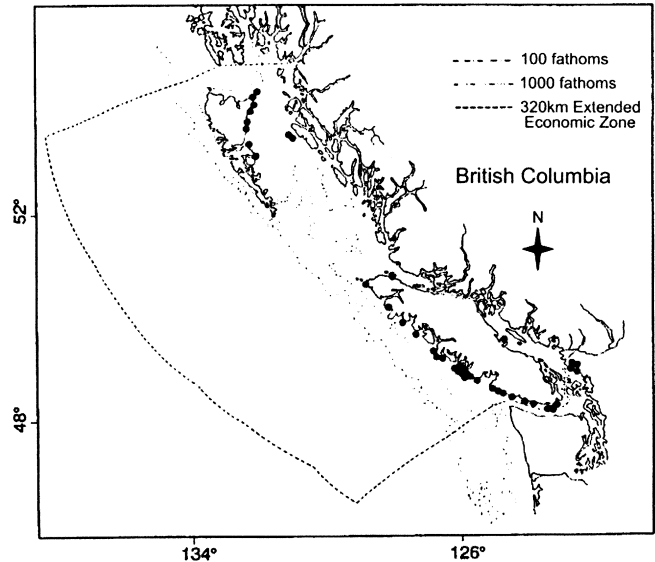


Fig. 1. Map showing locations of stranded and dead floating gray whales in BC. See Table 4 for details.

The cause of death was determined only for animals killed either in encounters with fishing gear, or in one case of two animals probably attacked by killer whales. Necropsies were not undertaken on many animals and even when they were, decay of the animal, or other factors, made positive determination of cause of death difficult. Of the 15 dead gray whales listed in Table 4 which were examined closely, cause of death for four (27%) was determined to be due to incidental catches in fisheries (but see Discussion for biases in this estimate).

Several records in Table 4 warrant further comment. Hatler (1972) mentions a photograph (No.60) (in a photo-duplicate file originally at UBC, now at RBCM) of an unpublished stranding of a gray whale from Long Beach, Vancouver Island, in the fall of 1957. However, examination of the photograph for this study revealed that although the photograph was labelled as a gray whale, the animal was in fact a sperm whale (*Physeter macrocephalus*). Campbell and Stirling (1971) mention a photograph of a stranded gray whale in the photo-duplicate file, but present no details. Further examination of photographs in this file indicate that this record is the same as that presented by Pike and MacAskie (1969), of an animal from August 1966 at Wreck Bay (also called Florencia Bay), on Vancouver Island. The file contains two records from this date, photo No.65 from near Green Point, Long Beach and No.427 from Wreck Bay. Hatler (1972) reported that the Long Beach animal (record No.65) had an estimated length of 40ft (12.19m). Examination of the photographs for this study revealed that these are duplicate records of a single animal, with a measured length of 27ft (8.24m) (presented in Pike and MacAskie, 1969).

The data for the 1990-1995 period ($n = 40$) are given in Table 5. These are considered in the Discussion section below.

Table 4

Records of stranded and dead floating gray whales received from sources other than questionnaire up to 1989 (VI=Vancouver Island).

Date	Location	Latitude/longitude	Cause ¹	Type ²	Sex	Length ³	Source ⁴
16 Aug. 1966	Wreck/Florencia Bay, VI	49°0'N, 125°38'W	1	1	M	824	1, 2
1970s	Tofino, VI	49°9'N, 125°55'W	2	1	-	-	3 ⁵
Jun. 1971	Sandspit, Moresby I.	53°15'N, 131°48'W	2	1	-	-	4
25 Apr. 1976	Jordan River, VI	48°25'N, 124°3'W	2	1	F	-	2, 5
19 Jun. 1979	Rose Spit, Graham I.	54°10'N, 131°40'W	1	2	M	850	6 ⁶
19 Jun. 1979	Rose Spit, Graham I.	54°12'N, 131°38'W	1	2	F	790	6 ⁶
29 Dec. 1980	Bonilla I.	53°29'N, 130°38'W	1	3	-	442e	6
30 Mar. 1982	Cloose, VI	48°39'N, 124°48'W	2	1	F	862	2 ⁷
04 Mar. 1983	Vargas I.	49°11'N, 126°0'W	2	1	-	1,295e	6, 7 ⁸
17 Mar. 1983	Tatchu Pt, VI	49°51'N, 127°8'W	2	1	M	1,280	6
Apr. 1983	China Beach, VI	48°27'N, 124°10'W	3	4	F	-	8
16 Apr. 1983	Oenander R., Graham I.	53°39'N, 131°55'W	2	1	M	1,200e	7
17 May 1983	Estevan Pt, VI	49°22'N, 126°32'W	3	5	-	790e	6, 7
2 Mar. 1984	Vargas I.	49°9'N, 125°59'W	2	1	-	660e	6, 9 ⁹
8 Mar. 1984	Metchosin, VI	48°25'N, 123°28'W	1	1	F	800e	8, 10 ¹⁰
24 Apr. 1984	Boundary Bay	49°3'N, 122°56'W	3	4	F	950e	6, 10
26 Apr. 1984	Boundary Bay	49°4'N, 123°0'W	2	1	-	850e	6, 10
4 Jun. 1984	White Rock	49°1'N, 122°48'W	2	1	F	909	6, 10
5 Jun. 1984	Boundary Bay	49°5'N, 122°54'W	2	1	-	600e	6, 10
9 Sep. 1984	West Coast Trail, VI	48°40'N, 125°W	2	1	-	-	11
20 Jan. 1985	Bonilla I.	53°29'N, 130°37'W	2	1	-	-	8
Sep. 1985	Side Bay, VI	50°20'N, 127°52'W	2	1	-	792e	8 ¹¹
16 Apr. 1986	Tofino, VI	49°7'N 125°54'W	2	1	M	900e	6, 12
May 1987	Estevan Pt, VI	49°23'N, 126°31'W	2	1	-	-	6, 13, 14
1 Sep. 1987	Kyuquot, VI	50°N, 127°20'W	2	1	-	1,370e	6, 13, 14
17 Sep. 1987	Long Beach, VI	49°2'N, 125°40'W	2	1	-	610	6, 13
7 Oct. 1987	Tofino, VI	49°10'N, 125°55'W	2	6	-	760e	6
1 May 1988	Bonilla Pt, VI	48°35'N, 124°43'W	1	1	-	680	15 ¹²
19 May 1988	Denman I.	49°30'N, 124°41'W	1	6	M	750	15 ¹³
24 May 1988	Graham I.	53°30'N, 131°50'W	2	1	-	-	15
4 Aug. 1988	Cape Scott, VI	50°47'N, 128°21'W	3	4	-	800e	16
20 Aug. 1988	Goletas Ch., VI	50°50'N, 127°45'W	2	1	-	800e	6, 15 ¹⁴
Jan. 1989	Estevan Pt, VI	49°23'N, 126°30'W	2	1	-	-	16
Jan. 1989	Cape Fife, Graham I.	54°5'N, 131°40'W	2	1	-	-	16
Jan. 1989	Cape Fife, Graham I.	54°5'N, 131°40'W	2	1	-	-	16
1 Jun. 1989	Cumshewa Hd, Moresby I.	53°1'N, 131°33'W	2	6	-	-	16
6 Jun. 1989	Echachis I.	49°7'N, 125°56'W	2	1	-	1,250e	16
7 Jun. 1989	Sooke, VI	48°19'N, 123°40'W	1	1	M	1,260	16 ¹⁵
5 Jul. 1989	Pachena Pt, VI	48°43'N, 125°5'W	1	1	M	-	6, 16
23 Aug. 1989	Ucluelet, VI	48°57'N, 125°35'W	2	6	-	-	16
29 Oct. 1989	Sooke, VI	48°19'N, 123°40'W	1	6	F	1,200e	16 ¹⁶

¹ 1 = examined closely by original observer with no signs of incidental catch; 2 = not examined closely; 3 = incidental catch.

² 1 = found dead on beach, no obvious cause of death; 2 = found dead on beach, possible cause of death due to killer whale attack (body extensively covered with tooth rakes); 3 = live stranding, died - note the total length indicates a new born calf; 4 = lines wrapped around tail and/or body, possibly from trap or troll fishery; 5 = gillnet wrapped around tail; 6 = found floating dead, no obvious cause of death.

³ If the length was estimated or it was unclear that length was standard, then the measure (in centimetres) is followed by 'e'.

⁴ 1. Pike and MacAskie, 1969; 2. Royal British Columbia Museum; 3. A. Barton, Simon Fraser University; 4. N.&A. Carey; 5. Darling, 1977, p.40; 6. Notes and/or photographs in files of M. Bigg, Pacific Biological Station; 7. Goodman, 1984; 8. Stranded Whale and Dolphin Program of BC, c/o authors; 9. Bamfield Marine Station; 10. Canada, 1985; 11. Pacific Rim National Park; 12. Mansfield, 1987; 13. Baird *et al.*, 1988; 14. Canada, 1988; 15. Stacey *et al.*, 1989; 16. Langelier *et al.*, 1990.

⁵ Skull in Simon Fraser University Zooarchaeology Collection, Burnaby, BC. No. T00307.

⁶ Partial skeletons at Queen Charlotte Islands Museum, Skidegate, BC. Both animals had extensive tooth rakes and bite marks, and appeared to have been attacked by killer whales.

⁷ Skull at Royal British Columbia Museum, Victoria, BC. (BCMP No. 11310).

⁸ Goodman (1984), based on data compiled by M. Bigg, reports the length of this animal as 27' (820cm). Notes in the files of M. Bigg, however, identify this animal as being measured at 42.5' (1,295cm).

⁹ Skeleton at Bamfield Marine Station, Bamfield, BC.

¹⁰ Skeleton collected by International Cetacean Watch Society, skull and partial skeleton at Sidney Marine Mammal and Historical Museum, Sidney, BC; partial skeleton at Stranded Whale and Dolphin Program of BC.

¹¹ Skull at Nanaimo Montessori School, Nanaimo, BC

¹² Skeleton at Wickaninish Interpretive Center, Pacific Rim National Park, BC.

¹³ Skull at North Island Wildlife Recovery Center, Errington, BC, collected by Stranded Whale and Dolphin Program of BC. (SWDP No. 88-05).

¹⁴ Skull at Stubbs Island Charters, Telegraph Cove, BC. (SWDP No. 88-10).

¹⁵ Skeleton at Edward Milne School, Sooke, BC. (SWDP No. 89-10).

¹⁶ Skeleton at Lester B. Pearson College of the Pacific, Victoria, BC. (SWDP No. 89-29).

DISCUSSION

Questionnaire data

For a general discussion of the use of questionnaire surveys in such studies, see Lien *et al.* (1994). The 16% response rate to the questionnaire represents a relatively high return for studies of this nature (*cf.* Heide-Jørgensen, 1988). Potential bias resulting from non-response patterns is difficult to control in this type of survey. A certain measure of resilience to the unknown influence of those who did not respond can be taken from the proportion of responses in each fishing gear category. As Table 1 indicates, the return rate is the same across the three largest fisheries: seine, gillnet and troll, and varies only in the smaller groups. The lowest return rate came from the shrimp trap fishery. Although there are no records of gray whales entangled in shrimp trap gear, a humpback whale became entangled in shrimp trap gear in 1989 (Langelier *et al.*, 1990). Some respondents did not specify which type of trap or trawl they used and the records were subsequently excluded from the analyses. This probably accounts for the low response for these categories. As trap and longline gear is set for up to two days without being monitored by the fishermen, gray whale entanglements with those gear types could remain unrecorded, when, for example, gear would disappear for no obvious reason. However, no data are available to estimate the magnitude of this bias. A bias in extrapolating from the total number of licences issued is that many fisheries are limited entry fisheries and some fishermen apply for licences without using them, to retain the ability to use the licences in the future. Again, no data are available to estimate the proportion of licences not being used, but this would tend to result in an overestimate of gray whale mortality.

Other biases inherent in social surveys include limitations of recall, inclusion of socially or politically desirable responses, or simply a cultural bias against perceived management intrusion within the fishing society (Lien *et al.*, 1994). The latter two possibilities represent a strategic response bias. Given the relatively high rate of return, the number of respondents that included their name and address and the number of additional and helpful unsolicited comments, the information received is believed to be accurate and largely free from uni-directional bias.

Fishermen may have regarded this as a good opportunity to voice their concerns about gear damage due to whale incidents, which would have biased the number of incidents reported upwards. On the other hand, fishermen may not have wanted to make it known that gray whales or other cetaceans were coming into contact with their gear, especially when it resulted in injury or death to the animal. Heide-Jørgensen (1988), in discussing his mailed survey regarding killer whales in Greenland, remarks that the small response to his questionnaire (7%) may have been due to people not being inclined to return a questionnaire when they have no information to provide. This potential bias may have been offset in the survey used for this study by the inclusion of question No.1. Many respondents could have answered it affirmatively and thereby felt that they were contributing some information.

In designing the survey, it was assumed that there would be a trade-off between the ease of filling out a questionnaire and the magnitude of the response to it. To obtain more detailed data from the questionnaire regarding gear type, years fishing, identification of animals involved in gear collisions and resultant mortality, specific categories could have been included. However, with the anticipated low number of gray whale incidents, inclusion of such details

would result in a decrease in the number of responses, to the point that the resultant mortality estimate would have been less accurate.

Some inaccuracy may result from the inability of the observer to assess the amount of injury, especially internal or stress-related, associated with incidents. An underestimate of mortality may be present due to the fact that a percentage of animals in the category 'released unharmed' probably suffered some injury of this nature. Therefore, this category may contain some animals that later died as a result of the incident. Mortality at a later date due to entangled gear might also occur, as evidenced by a gray whale reported by Geiger and Jeffries (1983), which apparently entangled in a shark gillnet off California and drowned in Washington when the net snagged on bridge supports. Similarly, Table 5 reveals two animals that had died later, one entangled in a Mexican gillnet fishery and one possibly in a US swordfish (*Xiphias gladius*) net in 1994.

An additional potential bias in the results arises from the ability of the respondents to identify gray whales accurately. Included in the questionnaire was a question asking about entanglements of other species of cetaceans. Responses were received of gear collision incidents with 350 small cetaceans (Stacey *et al.*, 1990; 1997), as well as with 11 humpbacks (*Megaptera novaeangliae*) and 10 killer whales (*Orcinus orca*). There were also reports of incidents involving 13 unidentified cetaceans, 10 of them large whales. Two additional species, one minke whale (*Balaenoptera acutorostrata*) and one sei whale (*B. borealis*) were mentioned by respondents recalling secondhand reports of incidents. In light of these responses showing the ability of at least some fishermen to discriminate between species of large whales, it was assumed that the identifications of gray whales were accurate. We did not pro rate the unidentified large cetacean records using the relative proportion of gray whales to other large cetaceans because of possibly incomplete data, as many respondents might not have fully completed the questionnaire if they did not have any gray whale incidents to report in question No.2. It is likely that some of the unidentified animals were gray whales but, considering that some of the records identified as gray whales may have been misidentified, it was not possible to predict the direction or magnitude of these biases.

Stranding data

Biases in previously collected stranding data render its usefulness in evaluating true levels of incidental mortality questionable. However, a properly designed future study could answer such questions more efficiently. Knowledge of mortality levels from independent sources such as questionnaire surveys are important in understanding what proportion of animals killed in fishing gear either sink, are eaten by scavengers, float offshore, or strand but are never found. Thus, the examination of stranded animals will only provide a minimum estimate of animals killed in fisheries. One consideration is the geographical scope involved when examining stranded animals. Some animals killed in fisheries in BC will probably wash up to the north in Alaska or to the south in Washington State. Similarly, some animals which wash up in BC have probably been killed in US fisheries. Presumably however, if efforts and type of fishing are similar in all three areas, such biases would not be uni-directional. There used to be little effort put into monitoring strandings in southeast Alaska, so such events there are probably not recorded (J. Sease, NMFS, Juneau, pers. comm., 1990). In Washington State, floating dead whales are not typically recorded unless they wash up on

Table 5

Strandings and incidental catches of gray whales from 1990-1995. V.I. = Vancouver Island.

Date ¹	Location ²	Comments ³
25 Mar 1990	Hesquiat Harbor, V.I.	C,u
05 Apr 1990	Kettle In., Aristazabal I.	C,u
18 Apr 1990	Esperanza In., V.I.	F,u
28 May 1990	Raft Cove, V.I.	C,u
31 May 1990	S Sombrio Pt., V.I.	C,u
01 Jun 1990	Ferrer Pt., Nootka I.	C,u
06 Jun 1990	South Beach, Graham I.	C,f
11 Jun 1990	Kitasu Bay, Swindle I.	A (herring net pen),u
27 Jun 1990	Miller Creek, Graham I.	C,f
29 Jun 1990	Weibe I.	C,D,u
01 Jul 1990	Hecate Strait	C,u
18 Jul 1990	2 mi. E. Lookout I.	C,f
24 Jul 1990	Lennard I.	C,f
26 Jul 1990*	7 mi. W Cape Beale, V.I.	C,u
20 Mar 1991	Hesquiat, V.I.	C,m
23 Mar 1991	Cleland I.	E (herring set gillnet)
27 Apr 1991	Pulteney Pt., Malcolm I.	C,f
12 May 1991	Boundary Bay	C,f
11 Jul 1991	Nuchatlitz Inlet, Nootka I.	C,m
18 Jul 1991	Orveas Bay, V.I.	C,m
29 Apr 1992	Stanley Park, English Bay	F? (27 April),m
24 May 1992	Cape Perkins, V.I.	C,m
1 Jun 1992	Port Clements, Graham I.	C,f,P
3 Jun 1992	Union Bay, V.I.	C, m
Ca 17 Jun 1992	Tlell, Graham I.	C,D,u
31 Aug 1992	Radar Beach, V.I.	C,m
19 Dec 1992	Higgins Passage, Price I.	C,D,f
1 May 1993*	~ 46km WSW Tofino, V.I.	C,D,u
8 Aug 1993	Smith Inlet	E (salmon drift gillnet),u
17 Apr 1994	Dare Point, V.I.	A,D,u,814cm (Mexican gillnet fishery)
27 Apr 1994	2km S Dare Point, V.I.	C,D,u,1158cm
5 May 1994	Port San Juan, V.I.	A,D,u,(US swordfish net?)
13 May 1994	Nootka I.	C,D,u
3 Jun 1994	Jordan River, V.I.	C,D,f,730cm
8 Jun 1994	N Eagle Creek, Graham I.	C,D,u
8 Apr 1995	Winter Harbour, V.I.	C,u
14 Apr 1995	Jordan River, V.I.	C,D,u
June 1995	Kitasu Bay	C,D,u
18 Jun 1995	Boundary Bay	C,D,u
10 Jul 1995	Off Winter Harbour, V.I.	C,D,u

¹Date shown is earliest date reported. Many records were also reported seen either on shore or floating from later dates. Similarly, some animals may have been dead for up to a month when first reported. ²Location is last known location. In some cases, animals were seen floating on one day, with later reports of what we believe is the same animal washed up nearby. ³Comments: Length shown if known. A: incidental catch, died; B: live stranded, died; C: found dead; D: not recovered; E: incidental catch, released alive; F: live stranded, returned to water alive; sex: f=female, m=male, u=unknown. *Some doubt over identity of animal. Precise location details can be obtained from the Stranded Whale and Dolphin Program of British Columbia.

shore (R.C. Ferrero, NMFS, Seattle, pers. comm., 1990). This is another source of error leading to a low estimation of deaths and thus of incidental mortality. In addition, animals may wash up in one location and be recorded, then wash back out and be recorded elsewhere. Such biases are exacerbated by the lack of tagging of dead animals for re-identification and by a lack of communication between stranding programmes in the two adjoining countries. More recently, effort has been put into looking at mortalities and fishery interactions in the USA (see Angliss *et al.*, 2001, table 24a,b).

Another potential bias in this method is that some signs of an incidental mortality, such as nets or lines wrapped around part of a whale, would be extremely obvious even if an

animal was not examined closely. Such signs may be visible months after the animal washed up on a beach. However, there have been no circumstances where an animal observed killed in fishing gear in BC has subsequently washed ashore and was examined. Several additional complications may also be important in determining cause of death. Some animals can be killed with little or no external signs of injury or associated entangled gear. Heyning and Lewis (1990) note two incidents off California which are relevant. In one case the net from an entangled dead floating gray whale was removed and the animal stranded the next day. However, it was impossible to determine the cause of death, even though the animal was examined closely. In another case, a dead floating animal seen with gear attached stranded 11 days later without gear. It is also possible that animals could get fishing gear entangled around an appendage without serious harm. Such gear might stay entangled indefinitely and animals dying from other causes would be recorded as killed incidentally in fishing gear. Moore *et al.* (1979) also noted that in areas with strong currents or high water flow (such as in river mouths), gray whales that had died from other causes could become entangled in gear; moribund gray whales dying from other causes might be less likely to actively avoid entangling in gear if such a situation arose. Thus, although the final cause of death might be from gear entanglement, mortality would have been inevitable. For these reasons it is not possible to predict the magnitude or direction of these biases and for the purposes of these analyses, it was assumed that animals with gear entangled on them died as a result.

The level of effort expended to record strandings varies along the 27,000km of BC coastline. Only two of the strandings reported in Table 4 are from the mainland coast of BC north of Vancouver Island, where effort is much lower than in the rest of the province. The large number of gray whale records towards the end of the period probably does not reflect an actual increase in the number of strandings, but rather increased effort. However, despite a considerable increase in effort, it is likely that only a small percentage of the animals washing up are recorded. Comparing stranding programmes elsewhere in North America and their levels of effort and the accessibility of coastline, the proportion of the total number of strandings in BC which get recorded is probably relatively low. The majority of the effort in responding to strandings has also been focused on more unusual species, or on species with higher research priorities, (e.g. killer whales) and on those in more accessible areas. However, the remains of large whales, such as the gray whale, may stay on a beach for months or years and thus the likelihood of them eventually being found and reported is higher than for smaller animals.

The number of gray whales reported dead each year can probably be best estimated from years when such events receive considerable publicity, or from more recent years as effort and awareness has increased. In 1984, following a chlorophenate spill in the Serpentine River near White Rock, BC, six gray whales were reported washed up dead in southern BC and an additional four animals were found in Washington State (Canada, 1985; Knox, 1985; Colodey, 1986; Table 4). Although no cause/effect relationship was found, such events appear to generate general public awareness, especially through the media and probably result in an increase in reporting. Although only a few stranded gray whales were recorded in 1985 and 1986, based on the number of strandings of other species recorded during those years (Stranded Whale and Dolphin Program of BC, unpubl. data) we believe this reflects a lack of effort in recording strandings, rather than an actual decrease in the number of

strandings. Based on a consideration of the low levels of effort in reporting and recording strandings, we believe the number recorded in 1989, nine individuals, best represents the typical number of gray whales washing up each year. This is supported from two sources. Firstly, Heyning and Dahlheim (In Press) noted that less than 5% of the estimated 1,407 gray whales that die annually in the eastern North Pacific are recorded in stranding records along the North American coast. Unless a highly disproportionate number die in even more isolated areas, such as in much of Alaska, the highest number recorded in one year from BC waters is still probably conservative. Secondly, effort in promoting the reporting of strandings in BC increased since 1987, as have the total number of all cetacean strandings. For example, the number of gray whale strandings recorded from 1990 – 1995 was about 40 individuals (Table 5) or about 7 per year. On this basis, the estimate of nine individuals is not unreasonable. Using this estimate of nine individuals and the estimated rate of 27% of such strandings resulting from incidental catches in fisheries, gives a crude estimate of minimum annual mortality of 2.4 individuals.

Of the four incidental catch records listed in Table 4, three appeared to have taken place during the northward migration and the fourth during the summer. Very little fishing is undertaken during the period of the southbound migration.

Several additional non-natural sources of mortality should be taken into account. One of these is mortality from collisions with vessels; for example, Moore *et al.* (1979) note one stranding off Washington State where vessel collision was implicated. Angliss *et al.* (2001) reported a ship strike in Alaska in 1997. Although this issue was not directly addressed in the questionnaire, there was no evidence from the stranding and questionnaire data that collisions with vessels might be an important mortality source in BC. An additional mortality source may be collisions with net pens used in aquaculture or fisheries, such as the herring spawn on kelp fishery in BC. Net pens used in salmon farms are typically located in areas which gray whales do not frequent, so few conflicts are likely to occur. Herring net pens on the other hand are set in areas where herring spawn and gray whales feed in these areas on roe. There is, for example, one record from June 1990, of a gray whale entangling and drowning in a herring pen on the central BC coast (P.F. Olesiuk, DFO, Nanaimo, pers. comm., 1990; Baird *et al.*, 1991). No other incidents are known of collisions with herring pens, but monitoring of this fishery for potential conflicts with gray whales is warranted. No reports of collisions with herring set gillnets were noted in the questionnaire returns, although some animals have probably been killed in this fishery; a live animal was photographed entangled in a herring set gillnet in March 1991 off Tofino, Vancouver Island (RWB own data).

CONCLUSIONS

Based on the results of the two methods, an estimate is derived of between 2 and 2.4 gray whales killed incidentally in BC commercial fisheries each year. Although there are some doubts as to the validity of questionnaire data (e.g. IWC, 1991), the estimate based on stranding data to some degree corroborates the use of the questionnaire survey in this case. However, there are numerous biases in both methods. Despite these biases, as Heyning and Lewis' (1990) examination of the incidental take off California, we conclude that the incidental take in Canadian waters appears to be very small relative to the population size. Even if both

methods produced estimates an order of magnitude lower than actual incidental mortality, this would still be the case.

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Analysing 25 years of bottlenose dolphin (*Tursiops truncatus*) strandings along the Atlantic coast of the USA: do historic records support the coastal migratory stock hypothesis?

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ABSTRACT

Between June 1987 and March 1988, bottlenose dolphins (*Tursiops truncatus* Montagu 1821) along the US Atlantic coast experienced an epizootic. Monthly interquartile ranges of strandings during the epizootic were used to propose the Coastal Migratory Stock (CMS) of bottlenose dolphins (Scott *et al.*, 1988). To date, the hypothesised CMS remains poorly understood. The goal of this study was to use a 25-year database to compare stranding patterns during the epizootic to those before (1972-1986) and after (1989-1997) the event. These comparisons reveal that monthly interquartile ranges during the epizootic are dissimilar to those before and after the event. The frequency distribution of total monthly strandings during the epizootic is also significantly different from those observed outside the event. Seasonal stranding patterns from 1989-1997 suggest more complex movements of dolphins along the US Atlantic coast than those of a single group ranging seasonally from Florida to New Jersey. In winter, for example, when the current model for the CMS predicts dolphin distributions concentrated in central Florida, the highest number of strandings occurred in North Carolina. Thus, these comparative analyses suggest that the pattern observed during the epizootic was anomalous, and not representative of stranding distributions for any other time period of the study. During the 15 years before the epizootic, and the nine years following, there was no clear picture of 'migration' of mortality along the coast. This study demonstrates how long-term, systematic collection of strandings data can be useful in testing hypotheses regarding the complex stock structure of coastal bottlenose dolphins. This knowledge will greatly enhance the ability to conserve and manage these animals as they recover from historic (i.e. directed takes and epizootic) and current sources of mortality.

KEYWORDS: STRANDINGS; BOTTLENOSE DOLPHIN; EPIZOOTIC; STOCK STRUCTURE; DISTRIBUTION; NORTH AMERICA; ATLANTIC OCEAN

INTRODUCTION

Strandings have historically provided one of the most readily available means to study the biology of marine mammals (e.g. Fraser, 1974; Reynolds and Odell, 1991; Malakoff, 2001). Strandings of bottlenose dolphins, *Tursiops truncatus* Montagu (1821), along the US Atlantic coast have been investigated from the late 1800s (True, 1889; 1891) to the late 1900s (Mead and Potter, 1990).

To date strandings data have been used only once in an effort to address bottlenose dolphin stock structure. The spatial and temporal distribution of strandings was described during a 10-month period from June 1987 to March 1988 (Scott *et al.*, 1988), when Atlantic coastal bottlenose dolphins experienced an epizootic (Geraci, 1989) that was later determined to be caused by morbillivirus (Duignan *et al.*, 1996; Schulman *et al.*, 1997). The mortality event, which was marked by elevated stranding rates, began in waters off Virginia, moved north to New Jersey in the summer, and then southward to central Florida in the winter (Fig. 1). Scott *et al.* (1988) used this pattern of elevated strandings, and the known distribution patterns of coastal dolphins north of Cape Hatteras, North Carolina (CeTAP, 1982), to hypothesise 'a single coastal-migratory stock of bottlenose dolphins that ranges seasonally as far north as Long Island, New York and as far south as central Florida'.

During the investigation of the 1987-1988 epizootic, 742 bottlenose dolphin strandings were reported — a ten-fold increase in strandings relative to the three previous years (Scott *et al.*, 1988). Scott *et al.* (1988) used this elevated

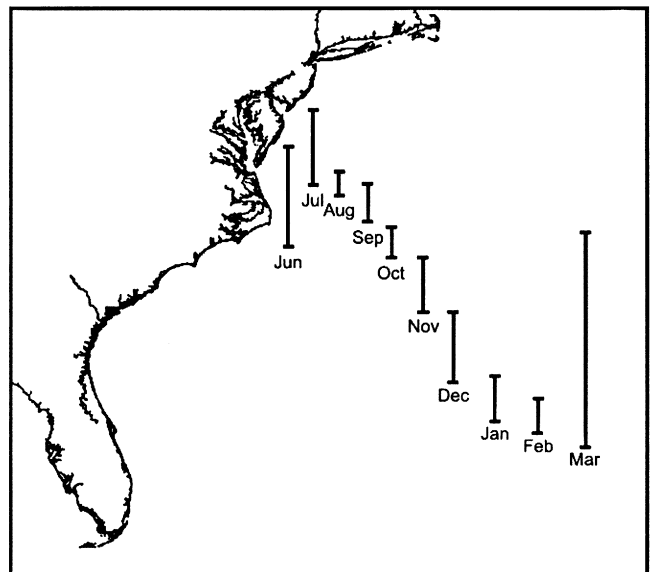


Fig. 1. Monthly interquartile latitudinal ranges of bottlenose dolphin strandings along the US Atlantic coast, June 1987 – March 1988 (from Scott *et al.*, 1988). The interquartiles show a movement of mortality north during the summer of 1987 and south during the autumn and winter.

stranding rate and assumptions regarding the birth and mortality rates of bottlenose dolphins (Hersh *et al.*, 1990), to conclude that the coastal migratory stock (CMS) had been

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reduced by over 50%. This finding led the National Marine Fisheries Service (NMFS) to determine that the CMS had fallen below its optimal sustainable population. Thus, it designated the CMS as depleted under provisions of the US Marine Mammal Protection Act (MMPA), and thereby required that a Conservation Plan be implemented to restore the stock to its pre-epizootic numbers (58 FR 177789, 6 April 1993).

Despite the definition proposed for the CMS, its structure, size and distribution remain poorly understood (Hohn, 1997; Barco *et al.*, 1999). A clear definition of bottlenose dolphin stocks along the east coast of the USA is vital, in that the Federal Government manages marine mammals on a stock by stock basis (e.g. Wade and Angliss, 1997). It is likely that the complex of coastal bottlenose dolphins, which inhabits estuarine and coastal waters from New Jersey to Florida, includes permanent residents as well as seasonal migrants (Hohn, 1997). Further, the relationship between the CMS and the recognised inshore form of bottlenose dolphins, i.e. the 'resident coastal population' (58 CFR 17789, 6 April 1993; reviewed by Hohn, 1997), has yet to be resolved. Cooperative, multi-agency, photo-identification efforts (Urian and Wells, 1996), and regional studies (Barco *et al.*, 1999) have demonstrated that individual dolphins exhibit considerable variation in patterns of movement and residency along the coast. Thus, a variety of alternate hypotheses describing the stock structure of coastal bottlenose dolphins are currently being considered (Fig. 2).

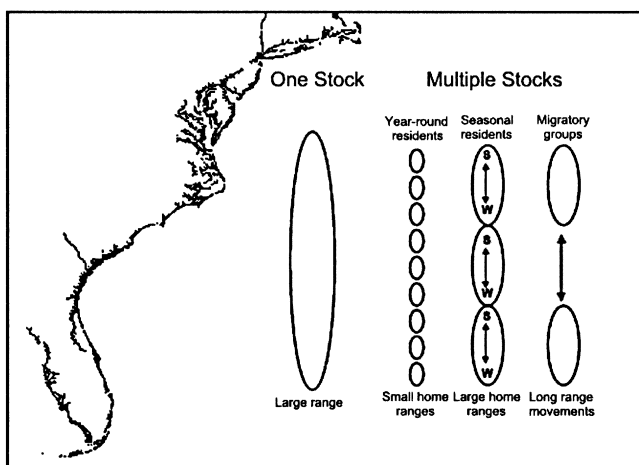


Fig. 2. Illustration of potential stock structures for bottlenose dolphins along the US Atlantic coast (redrawn from Hohn, 1997). Hypotheses include both single stock and multiple stock models (S = summer, W = winter).

The CMS was defined in the absence of any prior knowledge of its size, structure or distribution. Rather, it was defined by the spatial and temporal pattern of strandings which was assumed to represent the seasonal movements of a single group of dolphins along the Atlantic coast. Excluding the epizootic event, the spatial and temporal distribution of bottlenose dolphin strandings along the US Atlantic coast has not yet been described.

The goal of this study was to use a 25-year database (1972-1997) to compare the patterns of strandings observed during the 1987-1988 epizootic to those observed before and after this event to determine whether historical stranding records support the hypothesised CMS.

MATERIALS AND METHODS

Data for this study were taken from the Smithsonian Institution's Cetacean Stranding Database, which contained 4,521 coastal Atlantic bottlenose dolphin records from 1869-1998 (Table 1). These records included sightings, directed commercial takes from shore-based operations in North Carolina and stranding records from Florida to Maine. Stranding records from 1972, the year the national stranding network was established under the Marine Mammal Protection Act, to 1997 were analysed. Only 'strandings' (which eliminated 'sightings' and 'captures' from the original dataset) from the Atlantic coast of Florida (25°N) to New York (41°N), an area that represents the recognised geographic range of coastal Atlantic bottlenose dolphins (Wang *et al.*, 1994), were included in the analysis.

The subset of data used in this study was compared with both published and unpublished stranding records. After duplicate records were removed, the dataset was compared with compiled stranding records from Virginia (1991-1996; Swingle and Barco, 1997), Maryland (1992-1997; Susan Knowles, pers. comm.), South Carolina (1992-1997; Wayne McFee, pers. comm.) and the Southeastern United States Region (1993; Daniel Odell, pers. comm.). The resulting dataset consisted of all Atlantic bottlenose dolphin stranding records from 1972-1997 that contained the date, geographic position, sex and total length (termed 'Level A Data', as defined by Hoffman, 1991) of the stranded specimen.

Strandings were divided into three temporal blocks for analyses: (1) 1972-1986, a period of relatively low stranding response effort before the epizootic; (2) June 1987 – March 1988, the months of the epizootic when stranding response effort was extremely high; and (3) 1989-1997, a period after the epizootic when stranding effort remained high along the Atlantic coast. Although effort varied considerably among temporal blocks, effort within each temporal block was considered to be consistent.

Scott *et al.* (1988) used interquartiles to visualise the pattern of bottlenose dolphin strandings during the 1987-1988 epizootic. To permit direct comparison with Scott *et al.* (1988), latitudinal interquartiles for the months of June-March for each of the three temporal blocks defined above were generated (JMPIN 3.2.1, SAS Institute, Inc., NC). The interquartile plots for these three time blocks were compared to determine if the pattern observed during the epizootic (Scott *et al.*, 1988) was similar to that observed before and after the event.

An interquartile graphically represents only 50% of the data, including 25% of the observations above (in this case, north) and below (south) the median latitude for strandings. Whereas interquartiles represent normally distributed data well, they may misrepresent more complex distributions. To date, the distribution of bottlenose dolphin strandings along the Atlantic coast is not known for any time period. Therefore, total strandings, by month and by degree latitude, during the 1987-1988 epizootic were plotted. To compare these patterns with those before and after the epizootic, monthly strandings for 1972-1986 and for 1989-1997 were plotted and the frequency distributions compared using a chi-square analysis. All strandings from 1972-1997, and from 1989-1997 (the longest temporal block with consistently high effort), were also plotted by degree latitude to describe the overall pattern of strandings along the US Atlantic coast. A chi-square frequency distribution analysis was used to test whether the latitudinal distribution of strandings from the epizootic was similar to those during the other time periods. To examine the stranding data for

seasonal distribution patterns, the 1989-1997 data were plotted by degree latitude for each season (winter = December, January, February; spring = March, April, May; summer = June, July, August; autumn = September, October, November).

To test whether stranding distributions were simply a function of the amount of coastline per degree latitude, a linear regression analysis was performed to investigate the correlation between amount of coastline per degree latitude and number of strandings within that area. This analysis was performed on the stranding data from 1989-1997. To determine the amount of coastline in each degree of latitude, each degree was selected separately from a shape file of the US Atlantic coast using ArcView GIS 3.1 (ESRI Inc. California, USA), and the cumulative length of all polylines within that area was calculated.

RESULTS

The edited dataset for the years 1972-1997 contained a total of 3,763 Atlantic bottlenose dolphin stranding records, 3,358 of which were within the geographical range of the study and contained complete date, geographic position and total body length data (Table 1).

Table 1

Edits to original Smithsonian Institution's Cetacean Stranding Database used in this study.

Total unedited bottlenose dolphin records	4521
Total stranding records, 1972-1997	3783
Total edited records	3358
1972-1986	786
1987-1988	706
June 1987-March 1988 (epizootic)	667
Total strandings investigated	645
Total strandings with biological data	575
1989-1997	1819

From June 1987 to March 1988, the Smithsonian Institution recorded 667 stranded bottlenose dolphins along the US Atlantic coast, 75 less than the 742 dolphin strandings reported in Scott *et al.* (1988). Included among the 667 records were 22 reports of dolphin strandings with no accompanying data of any kind (no date, location, or biological data), which consisted of accounts from the public that were not investigated by a stranding response team. Thus, those 22 records were removed from the dataset leaving a total of 645. Of the 645 records, only the 575 that contained date, geographic position and total length data and were used in the interquartile analysis.

The monthly interquartiles for the 1987-1988 epizootic generated from this dataset (Fig. 3) are qualitatively similar (see Fig. 1) to those of Scott *et al.* (1988). In contrast, interquartiles for 1972-1986 and 1989-1997 are dissimilar to those of the epizootic event (Fig. 3). Except for the month of March, interquartile ranges before and after the epizootic encompass a larger geographic range than during the 1987-1988 event. The interquartile ranges for July and August during the epizootic do not overlap those before or after the event. During the epizootic, interquartiles were shifted north from June to September and south from December to February. Additionally, despite differing levels of stranding response, the 1972-1986 and 1989-1997 patterns are more similar to each other than either is to the

pattern observed during the epizootic. To ensure that patterns observed for these time blocks were representative of any given year, individual years were arbitrarily chosen and their interquartiles mapped (data not shown). None of these years showed interquartile patterns similar to those observed during the epizootic.

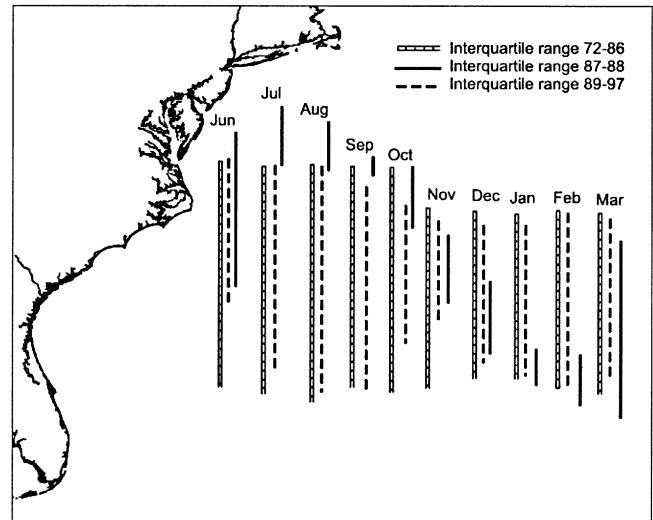


Fig. 3. Monthly latitudinal interquartile ranges (June through March) for bottlenose dolphin strandings from 1972-1986, 1987-1988 and 1989-1997.

Strandings during the epizootic event were distributed bi-modally, both by month and by degree latitude (Fig. 4). Strandings increased from June to August, tapered off through November, then increased again through January off the north-central Florida coast. Peak strandings occurred during August and at 36°N (Virginia Beach, Virginia); minimum numbers of strandings occurred in November and at 33°N (Cape Romain, South Carolina).

The frequency distribution of total monthly strandings observed during the epizootic was significantly different than the pattern observed during 1972-1986 ($p < 0.0001$) and during 1989-1997 ($p < 0.0001$) (Fig. 5). Monthly stranding patterns from 1972-1986 and 1989-1997 do not display the bi-modal distribution observed during the epizootic.

A latitudinal histogram of all strandings from 1972-1997 ($n = 3,358$) displayed a complex multimodal distribution with peaks from 34°N-36°N (Outer Banks of North Carolina to Virginia Beach, Virginia) and at 28°N (Cape Canaveral, Florida) (Fig. 6). Minimum numbers of strandings occurred at the northern and southern limits of the range and at the central latitudes of 33°N (near Cape Romain, South Carolina) and 31°N (near Brunswick, Georgia).

From 1989-1997, strandings ($n = 1,855$) plotted by degree latitude exhibited similar patterns to those for the entire dataset with peaks from 34°N-36°N and at 28°N (Fig. 7). Minimum numbers of strandings occurred at the northern and southern limits, and at 33°N and 31°N. A frequency distribution analysis of the latitudinal pattern of strandings from 1989-1997 was significantly different ($p < 0.0001$) than the pattern observed during the epizootic event (see Fig. 4C).

Seasonal patterns of strandings from 1989-1997 are complex (Fig. 8). In winter, few strandings occur north of 35°N (Cape Hatteras, North Carolina), a position with the largest number of strandings in that season. Irrespective of season, stranding numbers are always highest between

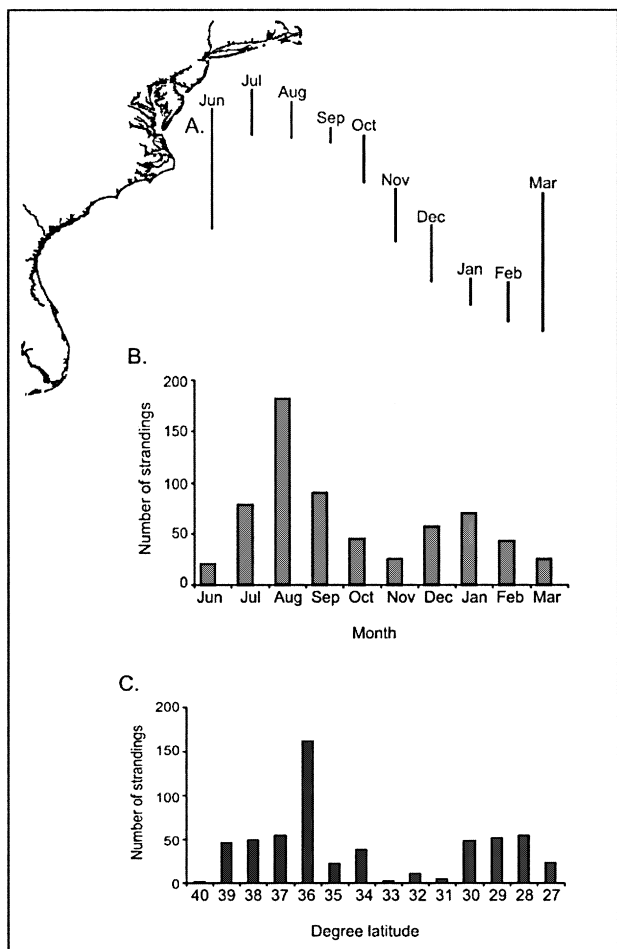


Fig. 4. Bottlenose dolphin stranding patterns during the 1987-1988 epizootic. (A) Monthly latitudinal interquartile ranges of bottlenose dolphin strandings from this study. (B) Histogram of monthly bottlenose dolphin strandings from June 1987-March 1988. (C) Latitudinal histogram of strandings from June 1987 - March 1988.

34°N-36°N, and at 28°N. Between these latitudes, minimum numbers of strandings occur at 31°N or 33°N (winter, spring and summer), and at 29°N in autumn.

A linear regression was performed to test whether the observed latitudinal frequency distributions of strandings were correlated with the amount of coastline in each degree of latitude. There was no significant correlation ($R^2 = 0.08$, $p = 0.25$) found between number of strandings and amount of coastline per degree of latitude.

DISCUSSION

The pattern of bottlenose dolphin strandings observed during the 1987-1988 epizootic, as represented by latitudinal interquartile ranges, was used to define the Coastal Migratory Stock (Scott *et al.*, 1988). These interquartiles, which represented a total of 742 strandings, showed a movement of mortality along the northern mid-Atlantic coast in July 1987. Mortality was concentrated off the coast of Virginia in August 1987 and continued southward in a stepwise fashion until concentrating again in north-central Florida in February 1988. When viewed in the context of the epizootic alone, these interquartiles show clear evidence of 'migrating' mortality northward in the summer and southward in the winter (Scott *et al.*, 1988) (Fig. 1 and Fig. 4A). The pattern of interquartiles generated in this study for

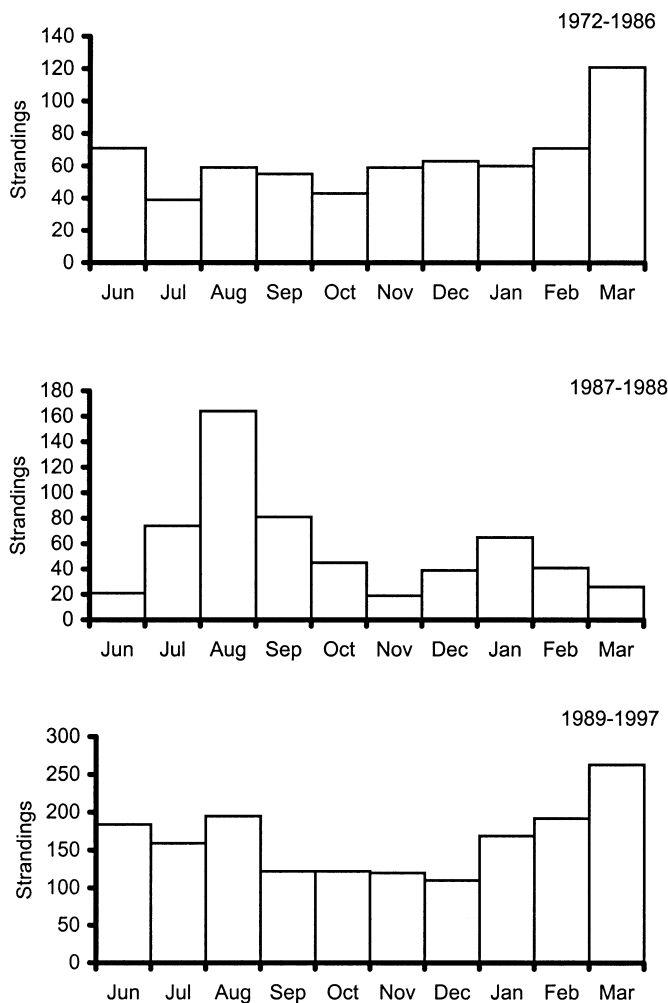


Fig. 5. Monthly histograms of bottlenose dolphin strandings before, during and after the epizootic (note that the y-axis scales differ for each time period).

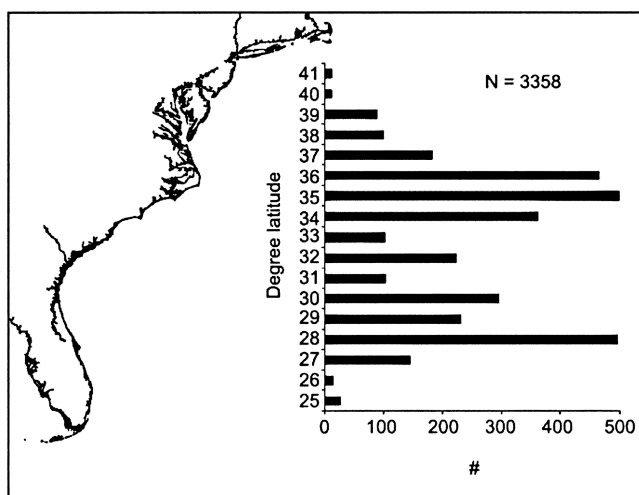


Fig. 6. Histogram of bottlenose dolphin strandings along the US Atlantic coast by degree of latitude, 1972-1997. The histogram is aligned relative to the coast line.

the epizootic, although based upon only 575 dolphin strandings, showed a similar seasonal movement of mortality along the coast.

Interestingly, this interquartile pattern is not observed for bottlenose dolphin strandings before or after the epizootic event. During the previous 15-year and subsequent nine-year

periods, there is no clear picture of 'migration' of mortality along the coast. The northern limits of the interquartiles do move south during the winter months, although they never advance farther than the central Outer Banks of North Carolina. The southern limits of the pre- and post-epizootic interquartiles are almost always farther south than those observed in 1987-1988. Similarly, no single year investigated showed interquartile patterns similar to those observed during the epizootic. Thus, the comparative interquartile analysis suggests that the pattern observed during the 1987-1988 epizootic was anomalous, and not representative of stranding distributions along the coast for any other time period.

However, interquartiles only illustrate 50% of the complete stranding dataset (25% above and below the median). In addition, as the median so heavily weights the

latitudinal placement of the interquartile, a concentration of mortality, as witnessed during the epizootic (Fig. 4), influences both its range and placement along the coast. Interquartiles also offer no information about the distribution pattern (e.g. uni- vs multi-modal) or the magnitude of strandings. These patterns can only be investigated by graphically representing the total stranding database.

During the 1987-1988 epizootic, both monthly and latitudinal distributions of strandings were bi-modal. Strandings peaked in August 1987, near Virginia Beach, Virginia, and again in January 1988, off central Florida. It is noteworthy that the centre of the November interquartile (and therefore the latitudinal median of all strandings during that month) is at 33°N, a latitudinal minimum for all bottlenose dolphin strandings in this study (Fig. 6). This distribution pattern of mortality is significantly different from those observed before and after the epizootic event. A minimum number of strandings occurred in November 1987, at Cape Romain, South Carolina (Fig. 4B and C). The monthly (Fig. 5) and latitudinal distributions of total strandings (1972-1997) and of strandings from 1989-1997 were more complex, with peaks occurring at the Outer Banks of North Carolina to Virginia Beach, Virginia, and at Cape Canaveral, Florida (Figs 6 and 7). Between these latitudes, minimum strandings occurred at 33°N, followed closely by 31°N. These distribution patterns are significantly different from the pattern observed during the epizootic event. Neither the interquartile pattern nor the monthly and latitudinal distribution patterns of strandings during the 1987-1988 epizootic are similar to those observed during the 15 years prior to and the nine years after the event; the migration of mortality illustrated by the 1987-1988 interquartiles does not typify mortality patterns for any other period of time investigated in this study.

From 1989-1997, seasonal stranding patterns (Fig. 8) also do not show a distribution that is consistent with the CMS

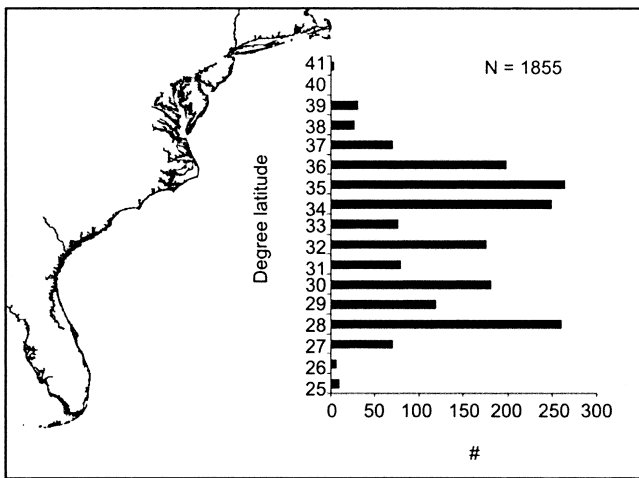


Fig. 7. Histogram of bottlenose dolphin strandings along the US Atlantic coast by degree of latitude, 1989-1997.

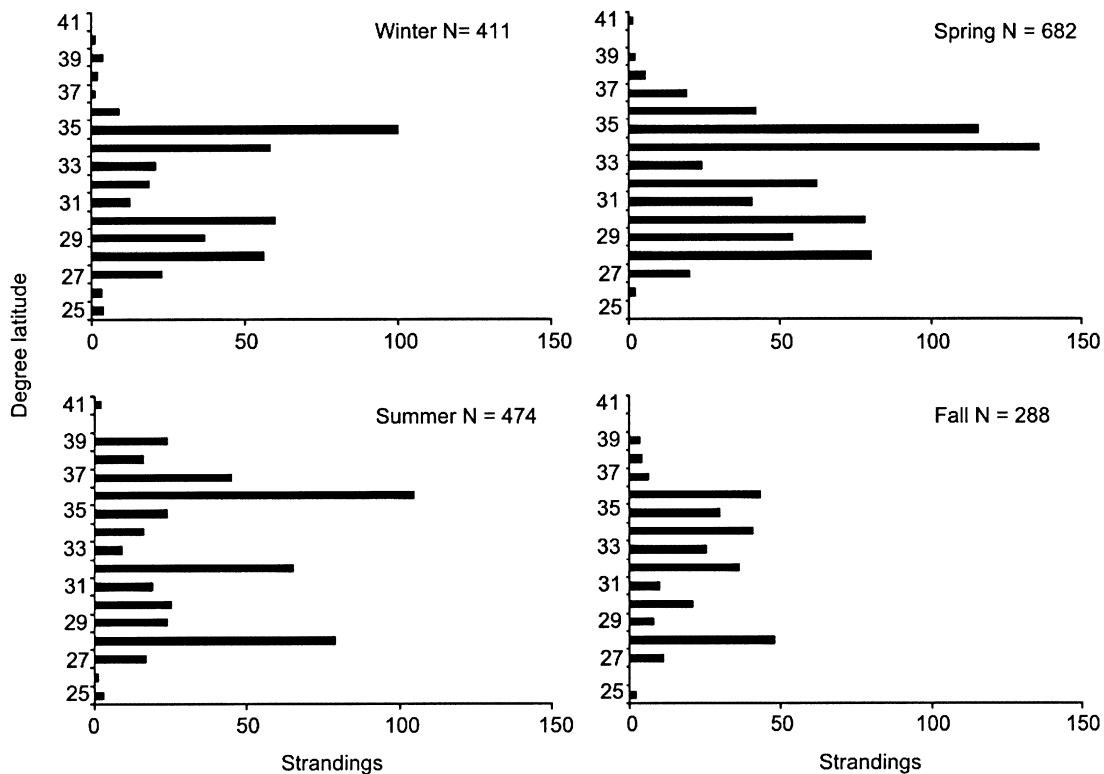


Fig. 8. Latitudinal histograms of bottlenose dolphin strandings for each season, for 1989-1997. Each season displays a complex distribution of strandings.

model of a stock of dolphins migrating north in summer and south in winter from New Jersey to Florida. In winter, for example, when the current model for the CMS predicts dolphin distribution concentrated in central Florida, the highest number of strandings occurred in North Carolina. In all seasons, the minimum number of strandings generally occurred at either 33°N or 31°N (although from 1989-1997 in autumn the minimum was at 29°N). These data suggest more complex movement patterns along the US Atlantic coast than that of a single group ranging seasonally from Florida to New Jersey.

Scott *et al.* (1988) reported that 742 dolphins were investigated during the epizootic. In conducting the analyses described here, only 667 stranding records for this time period were found to exist in the Smithsonian Institution's Cetacean Stranding Database. Of these, 22 records had no associated data of any kind, suggesting that the maximum number of dolphin carcasses investigated was 645. The discrepancy between the number of strandings reported during the 1987-1988 epizootic and the number taken from the same database for this study 12 years later may be explained by the continued editing and reassessment of the Smithsonian Institution's Cetacean Stranding Database.

Implicit in the analysis of the 1987-1988 epizootic was an assumption that spatial and temporal patterns of strandings represented seasonal movements of dolphins. Although this assumption may appear reasonable, especially given the extraordinary magnitude of the event, it is important to note that many factors may contribute to the distribution of carcasses along the coast. Stranding patterns may represent either real movement patterns of dolphins, and/or some combination of differential mortality rates, oceanographic currents that occur along the coast, or differential stranding response effort along the coast.

For example, the interquartile and distributional histograms of strandings may suggest a more complex stock structure or distributional pattern than that of a single coastal migratory stock. The seasonal histograms (Fig. 8) do suggest latitudinal movements of dolphins north of Cape Hatteras, North Carolina. These data support aerial (Kenney, 1990) and boat-based (Barco *et al.*, 1999) survey studies. In addition to this north-south movement pattern of coastal bottlenose dolphins north of Cape Hatteras, other factors may be contributing to the observed distributional patterns. These patterns may also represent dolphins moving seasonally between estuarine and coastal waters. Boat-based surveys conducted in Beaufort, North Carolina suggest that some dolphins spend summer months inhabiting estuaries and tidal rivers, and winter months in near-shore ocean waters (Rittmaster and Thayer, 1994). Dolphins stranding on ocean-facing beaches have a greater chance of being observed and recovered than those in estuarine areas. Stranding patterns are also influenced by mortalities of offshore bottlenose dolphins (Mead and Potter, 1995). The seasonal distribution patterns of offshore bottlenose dolphins have, to date, only been described from Cape Hatteras, North Carolina northward to Cape Cod, Massachusetts (Kenney, 1990). Offshore dolphins are known to range near the continental shelf and Gulf Stream current (Kenney, 1990), both of which are in close proximity to the coast near Cape Hatteras, North Carolina. Also, resident populations of bottlenose dolphins are known to exist along the US Atlantic coast (Petricig, 1995; Zolman, 1996) and contribute unknown numbers to the strandings database.

Another bias to the distributional patterns of strandings may come from differential mortality factors that may occur spatially or temporally. Entanglement in fishing gear is the

most common source of anthropogenic mortality for small cetaceans (Perrin *et al.*, 1994; Forney *et al.*, 1999; Hill and DeMaster, 1999; Read and Murray, 2000; Friedlaender *et al.*, 2001). The distribution and frequency of strandings may be influenced in areas where there is increased fishing effort (see Friedlaender *et al.*, 2001). The standardisation of protocols evaluating human-induced mortality as a cause of death (Haley and Read, 1993; Read and Murray, 2000) on all carcasses will enhance our understanding of the magnitude of this mortality factor in the stranding record.

Oceanographic and current patterns may also influence the observed frequency and distribution of strandings. Oceanographic features in certain coastal areas may either enhance or diminish the likelihood that a dead dolphin will strand on a beach. The slope and composition of a beach could greatly affect whether or not a dead dolphin would become beach-cast. Similarly, small and large-scale current patterns may confound the assumption that where a dolphin strands reflects where that dolphin died. A better understanding of these factors would be valuable in interpreting stranding patterns.

The final caveat to the distributions described from the stranding database is that of effort. Although the time blocks used in this study represent relatively consistent stranding response effort across years and throughout the entire Atlantic coast, it is likely that local effort can vary. There are areas along the coast that have been monitored consistently because long-term stranding programmes do exist, but other areas have not been monitored, usually because of accessibility. Areas with poor coverage and monitoring would be under-represented in the stranding record.

Historically, collection effort of beach-cast carcasses can be seen in the yearly contributions to the Smithsonian Institution's Cetacean Stranding Database from 1869-1997 (Fig. 9). Before 1972, the year of the enactment of the Marine Mammal Protection Act and the formalisation of stranding networks, contributions to the database came largely from collection efforts made on the Outer Banks of North Carolina during the time of a directed drive-fishery for coastal bottlenose dolphins (True, 1889; 1891). True recorded as many as 90 dolphins killed per day. This fishery operated from 1797-1920, and Mitchell (1975) estimated the cumulative catch of this fishery from 1885-1890 at 13,748 to 17,000 animals. This cumulative catch estimate has been mistakenly presented as a population estimate for coastal bottlenose dolphins up to the middle 1990s (e.g. Waring *et al.*, 1996)

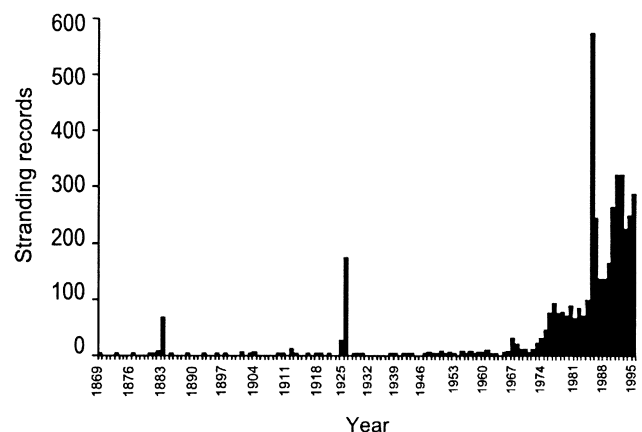


Fig. 9. Yearly records from the Smithsonian Institution's Cetacean Stranding Database, 1869-1997 ($n = 4,259$).

This study demonstrates how a long-term, systematic collection of strandings data can be useful in helping to understand the stock structure of coastal bottlenose dolphins. Such data can help formulate testable hypotheses regarding stock structure and provide information on long-term levels of mortality. However, the study has also shown that strandings data must be treated with proper caution when used to formulate hypotheses.

It is not clear from Level A strandings data (species, date, location, field number, sex, total body length) what combination of resident and migratory animals make up the stock complex of coastal bottlenose dolphins along the US Atlantic coast (e.g. Hohn, 1997). Genetic and morphometric analyses of stranded specimens might help to place individual animals into stocks, thus allowing a more detailed analysis of the stranding patterns (and therefore movement patterns) of specific stocks. The addition of genetic and morphometric sampling to basic stranding protocols would greatly enhance these efforts. Continued integration of stranding patterns, photo-ID efforts (e.g. Urian and Wells, 1996), telemetry and genetic analysis (with samples provided from stranded carcasses) will enhance our understanding of stock structure of coastal bottlenose dolphins along the US Atlantic coast.

Using the best available information at the time, Scott *et al.* (1988) concluded that the 1987-1988 epizootic 'primarily affected the coastal migratory stock of animals that ranges between Florida and New Jersey'. The results of this study do not support this hypothesis. The comparative interquartile analysis of stranding data suggests that the pattern observed during the 1987-1988 epizootic was anomalous, and not representative of stranding distributions along the coast for any other time period. Monthly and latitudinal frequency distributions of strandings before and after the epizootic are not similar to those observed during the event, and raise the question of how representative these stranding patterns are of a single stock of dolphins. Stranding patterns also suggest that coastal bottlenose dolphins do not form a single, discrete stock along the US Atlantic coast. This study demonstrates how long-term, systematic collection of strandings data can be useful in testing hypotheses regarding the complex stock structure of coastal bottlenose dolphins. This knowledge will greatly enhance our abilities to conserve and manage these animals as they recover from historic (i.e. directed takes and epizootic) and current sources of mortality.

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Behavioural responses of male killer whales to a ‘leapfrogging’ vessel

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ABSTRACT

The research and whalewatching communities of Johnstone Strait, British Columbia, Canada have worked closely together to identify whalewatching practices that minimise disturbance to northern resident killer whales. Local guidelines request that boaters approach whales no closer than 100m. Additionally, boaters are requested not to speed up when close to whales in order to place their boat in a whale’s predicted path: a practice known as ‘leapfrogging’. A land-based study was designed to test for behavioural responses of killer whales to an experimental vessel that leapfrogged a whale’s predicted path at distances greater than 100m. Ten male killer whales were repeatedly approached and the animals responded on average by adopting paths that were significantly less smooth and less straight than during preceding, control conditions. This adoption of a less ‘predictable’ path is consistent with animals attempting to evade the approaching boat, which may have negative energetic consequences for killer whales. The results support local consensus that leapfrogging is a disruptive style of whalewatching, and should be discouraged. Similarly, as the experimental boat increased speed to overtake the whale’s path, the source level of engine noise increased by 14dB. Assuming a standard spherical transmission loss model, the fast-moving boat would need to be 500m from the whale for the received sound level to be the same as that received from a slow-moving boat at 100m. Whalewatching guidelines should therefore encourage boaters to slow down around whales, and not to resume full speed while whales are within 500m.

KEYWORDS: KILLER WHALE; WHALEWATCHING; BEHAVIOUR; DISTURBANCE; REGULATIONS

INTRODUCTION

In 1993, the International Whaling Commission resolved ‘to encourage the further development of whalewatching as a sustainable use of cetacean resources’ (IWC, 1994). Tourism based on whalewatching has become a vital component of the economies of many coastal communities and shows potential to assist many more (Hoyt, 1997). Such tourism also affects attitudes toward protecting critical whale habitat and threatened populations (Barstow, 1986; Duffus and Dearden, 1993). However, a growing number of studies link vessel traffic with behavioural changes of whales, which may lead to increased energetic costs (Au and Green, 2001; Erbe, 2002; Williams *et al.*, 2002). As a result, resource managers must now consider a potential trade-off between economic and educational benefits of whalewatching and the habitat needs of whales.

Researchers have identified four distinct populations of killer whales (*Orcinus orca*) on the coast of British Columbia (BC), Canada. Despite having overlapping ranges, each population is socially and ecologically isolated (Ford *et al.*, 2000). Whalewatching operators in this region tend to focus on the northern and southern communities of resident killer whales (the fish-eating type), since these whales are found more reliably than ‘offshores’ or the marine-mammal-eating transients. A core summer area for northern resident killer whales and whalewatching activity is Johnstone Strait, off northeastern Vancouver Island, BC. Northern resident killer whales return here each year to socialise and to feed on migrating salmon (Nichol and Shackleton, 1996). A similar core whale and whalewatching area for southern residents is in Haro Strait between British

Columbia and Washington State (Hoelzel, 1993), where proximity to urban areas makes whalewatching a much larger industry than in Johnstone Strait.

The first whalewatching company to focus on killer whales began operation in 1980 in Johnstone Strait. The whalewatching and research communities of Johnstone Strait work together closely to identify whalewatching practices that minimise disturbance to whales. Local guidelines request that boaters parallel whales no closer than 100m; approach animals slowly, from the side; and not place boats in the path of a whale – a practice referred to in the guidelines as ‘leapfrogging’. Leapfrogging is a way of achieving a closest approach to a whale that is substantially closer than 100m. It complies with the letter of the distance guideline, but not its spirit.

In 1995 and 1996, Williams *et al.* (2002) experimentally approached killer whales to test the biological significance of the 100m parallel guideline. Results showed that killer whales used a suite of subtle tactics to evade a boat even at that distance, and that these avoidance patterns became more pronounced as boats approached closer (Williams *et al.*, 2002). Some boaters see leapfrogging as a benign means of getting close to whales without violating the 100m guideline. This has the added advantage from the tourists’ perspective of making it seem that whales are approaching the boat, which is the only way for boaters to watch whales closely without violating local guidelines. Other community members view leapfrogging as a potentially disruptive style of whalewatching.

It is of concern that leapfrogging may be at least as disruptive as parallel approaches. When speeding up to leapfrog, boat noise generally becomes more intense and

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higher in frequency (Richardson *et al.*, 1995), which offers greater potential to mask killer whale communication (Bain and Dahlheim, 1994) than slower, parallel approaches. Leapfrogging involves paralleling whales for some distance, at a faster speed than that of the whale, and then turning 90° to place the boat in the whale's predicted path. At this point, the leapfrogging manoeuvre places the noise source directly ahead of the whale, which is the position where masking effects may be greatest (Bain and Dahlheim, 1994).

Effective whalewatching guidelines must be biologically relevant and local communities in Johnstone Strait have endorsed a policy of experimental testing of various components of the guidelines. Northern resident killer whales generally adopted a more erratic surfacing pattern when an experimental vessel attempted to travel in parallel with them at 100m (Williams *et al.*, 2002). It was hypothesised that whales might respond to more intense whalewatching pressure by varying the duration of dives (vertical avoidance), or by swimming faster or altering the direction of swimming (horizontal avoidance). Whales might also display surface-active behaviours, such as slapping flukes or pectoral fins on the surface of the water. A more extensive study would be required to determine whether leapfrogging elicits stronger behavioural responses than other forms of whalewatching. Since commercial operators have agreed that leapfrogging is an inappropriate style of whalewatching, it should be necessary only to demonstrate that the technique is sufficiently disturbing to justify requesting that non-commercial whalewatchers also avoid leapfrogging.

This paper investigates whether a vessel that speeds up to leapfrog a whale's path, at a distance greater than 100m, alters the behaviour of northern resident killer whales that summer in Johnstone Strait.

MATERIALS AND METHODS

Study area

Data were collected between 28 July and 10 September 1998, from a land-based observation site on the south shore of West Cracroft Island in Johnstone Strait, British Columbia (50°30'N, 126°30'W; Fig. 1). Data were collected using an electronic theodolite (*Pentax* ETH-10D with a precision of ±10 seconds of arc) connected to a laptop computer equipped with custom software (THEOPROG; available from D.E. Bain). Cliff height and reliability of distance measurements were made using methods described by Davis *et al.* (1981) and Williams *et al.* (2002). The theodolite was located approximately 50m above mean sea level. The theodolite-computer apparatus measured the length of a 30m rope to be 28.93m ($n=20$, SE=0.18) at a distance of 3.79km. This translates to a measurement error of approximately 3.5% in terms of accuracy and < 1% in terms of precision. Percent errors in measuring cliff height, distance travelled and speed tend to be approximately equal (Würsig *et al.*, 1991).

Selection of focal animals

Northern resident killer whales enter the study area in social units referred to as matriline (Ford *et al.*, 2000). Matriline are generally dispersed with individuals spaced a few hundred metres apart, which is typical while foraging, the most commonly observed activity of resident killer whales in summer in Johnstone Strait (Nichol and Shackleton, 1996). Focal animals that could be re-sighted consistently were chosen. A focal animal typically had a distinctive dorsal fin and saddle patch (Bigg *et al.*, 1990). Only mature and

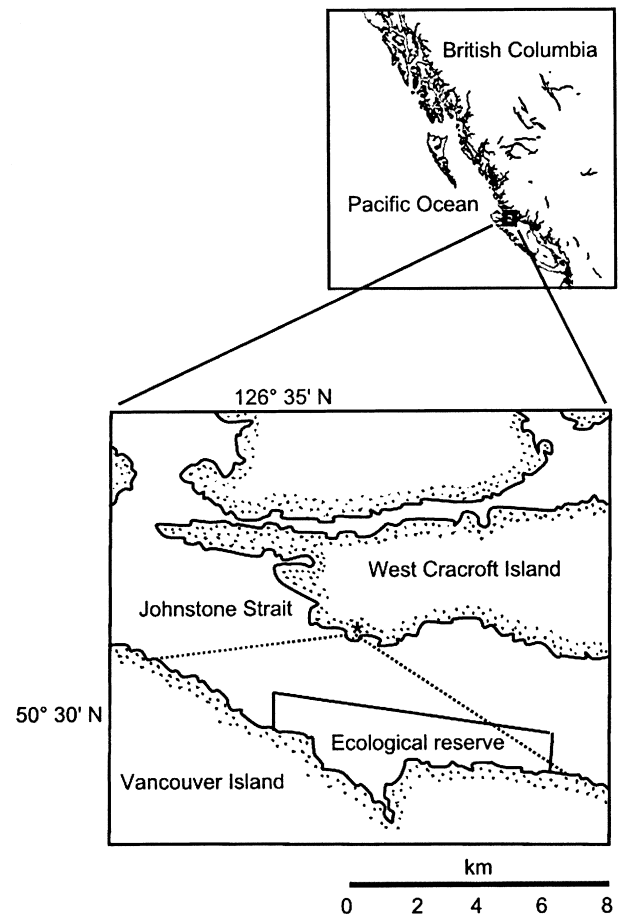


Fig. 1. Study area in Johnstone Strait, BC, Canada, showing lines of sight (.....), position of theodolite (*) and boundaries of Robson Bight – Michael Bigg Ecological Reserve.

subadult males were tracked in this study – they can be readily distinguished from other group members since their dorsal fins can reach twice the height of those of adult females. Animals were selected whose location within the study area made them likely to be visible for more than 15 minutes; earlier work has shown that tracks that are substantially shorter than 1,000s tend to bias estimates of respiration rate (Kriete, 1995).

Tracking

The tracking team consisted of a spotter, a theodolite operator and a computer operator. The spotter announced each time that a focal animal surfaced to breathe or display surface-active behaviour, and recorded tide height approximately every 15 minutes. The theodolite operator located the position of the whale during the surfacing. Events recorded by the computer operator included: breath, breach, fluke slap, pectoral fin slap, dorsal fin slap, unidentified splash, porpoising and spy-hop (Ford *et al.*, 2000). The computer was linked to the theodolite to record the time that it retrieved the horizontal and vertical angle co-ordinates of a whale's position. After approximately 15 minutes of no-boat, control observations, the computer operator requested (via VHF radio) that the experimental boat operator approach the focal animal.

Local whalewatch operators agreed to stay well clear (> 1 n.mile) of the focal animals while whale behaviour was recorded under control, no-boat conditions. The experimental boat was a 5.2m rigid-hull *Zodiac* inflatable

with a 90hp Mercury 2-stroke outboard engine. The boat operator was instructed to approach the focal whale slowly, from the side, and then run a course parallel to the whale at approximately 100m. THEOPROG was customised to display the distance between the last two positions as they were collected. After approximately 5-10 minutes, the computer operator asked the boat operator to speed up to overtake the whale. When the distance between boat and whale reached approximately 200m (ahead and to the side of the whale), the boat operator placed the boat directly in the whale's predicted path (completing the leapfrogging manoeuvre). Once the boat was in position, the operator shifted the engine into neutral and left the engine idling as the whale swam past. The boat operator made no sudden direction changes, and was in frequent VHF radio contact with the cliff-based observers. When the whale had swum approximately 500m past the experimental boat, the process was repeated twice more. After the third leapfrog, the operator shut off the engine when the whale was approximately 500m from the boat. The entire treatment period lasted approximately 20 minutes, depending on the whale's swimming speed.

Acoustic monitoring of the experimental vessel

The source and received levels and frequency spectra were calculated from DAT recordings made of the experimental boat under slow (i.e. paralleling speed) and fast (i.e. leapfrogging speed) conditions. A 2m, 15-element calibrated hydrophone array and on-board recording system, both flat to 24kHz, was towed from a recording boat (Miller and Tyack, 1998). The experimental boat operator was instructed to approach the recording boat slowly, at approximately 3kn speed as indicated by a *Magellan 2000XL* handheld GPS. The operator then accelerated towards the recording boat at the throttle position typically used to leapfrog a whale's position. As the experimental boat approached the recording boat, parallel to the hydrophone array, the recorders measured distance to the experimental boat using *Bushnell* laser rangefinders. When the distance reached 100m, a 2s sample of the recording was digitised for subsequent spectral analyses.

Data compilation

A mean dive time (i.e. average time between surfacings) was calculated for each track. The average swimming speed of the whale was obtained by dividing the total distance travelled by the duration of the tracking session. Two measures of path predictability were calculated: a 'directness index' and a 'deviation index' (Fig. 2; Williams *et al.*, 2002).

The directness index is 100 times the ratio of the distance between beginning- and end-points of a path to the cumulative surface distance covered by all dives. It is the inverse of the milling index of Tyack (1982) and Kruse (1991) and ranges from zero (a circular path) to 100 (a straight line).

The deviation index is the mean of all angles between adjacent dives, and can be considered an inverse measure of a path's smoothness. For each surfacing in a track, the angle was calculated between the path taken by a dive and the straight-line path predicted by the dive before it (Williams *et al.*, 2002). The deviation index is the mean of the absolute value of each of these discrepancies, in degrees, during the entire track. A low deviation index indicates a smooth path, while a high deviation index indicates an erratic path. Indices

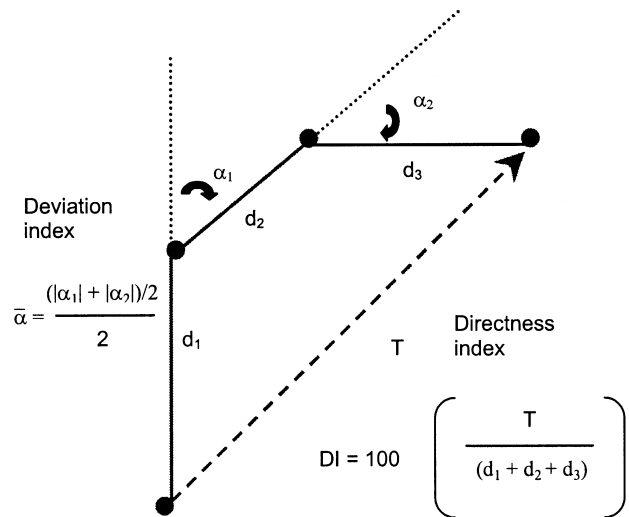


Fig. 2. A sample swimming path with four surfacings (●) and three dives (d_i), showing two measures of path predictability: deviation and directness. The deviation index is the mean of all angles between observed dives and the straight-line paths predicted (---) by preceding dives. The directness index is 100 times the ratio of the track diameter (T) to its perimeter.

of directness and deviation were calculated for each track. A track that shows high deviation and high directness is erratic but directional, whereas a track with low deviation and low directness is smooth but non-directional.

A record was taken each time surface-active events such as spy-hopping or breaching took place. A bout of tail-or fin-slapping was scored as one event if more than one slap took place during a surfacing.

Data analysis

Mean values for each dependent variable were averaged across all observations for an individual, such that each whale was represented only once. Variables recorded under control and experimental conditions were compared using two-tailed, paired *t*-tests. Comparisons were made only when at least 20 minutes of baseline, control observation was followed by an experimental approach of the same whale lasting at least 20 minutes.

RESULTS

Behavioural responses of killer whales to leapfrogging vessel

A total of 12 paired (control-treatment) observations were made of 10 male killer whales (Table 1). Earlier work (Williams *et al.*, 2002) has demonstrated the potential for sex-based differences in boat-avoidance tactics, if not boat tolerance. Consequently, two experimental approaches of female killer whales were excluded from the analyses. Whales responded to a leapfrogging vessel by adopting a path that was significantly less direct ($t_9 = 3.41$, $p = 0.007$), and the mean angle between successive surfacings became significantly greater ($t_9 = -5.29$, $p = 0.001$) than during the preceding, control period (Fig. 3). No significant difference was observed between whale behaviour during control and leapfrog conditions in terms of mean dive time ($t_9 = 0.42$, $p = 0.684$), swim speed ($t_9 = 0.29$, $p = 0.775$) or rate of surface-active behaviour ($t_9 = -1.76$, $p = 0.113$). However,

the power of these tests is low because of the small sample size. Beta probabilities (the probability of accepting a false null hypothesis) were high in the last three trials ($\beta = 0.941, 0.944$ and 0.568 , respectively). This suggests that if these mean and standard deviations were the true values, sample sizes of 1,408, 1,978 and 33, respectively, would be needed to conclude that the differences were significant.

Experimental boat noise

As the experimental boat approached the recording boat at slow speed, the theodolite tracking crew recorded its position 10 times along its path. Mean speed was 5.2km/h (± 1.02 SE). This agrees roughly with the 3kn (5.6km/h) average speed as measured by the GPS. During the high-speed approach, the theodolite team recorded 16 positions, and the measured boat's speed was 23.3km/h (± 1.79 SE). Again, this is corroborated by the simultaneous GPS measure of 12-13kn (22.2-24.1km/h).

Table 1

Number of pairs of observations (control vs. treatment) for each subject. Values were averaged for animals that were approached twice, such that each subject was represented only once in our analyses. Subjects' ages calculated from presumed year of birth reported by Ford *et al* (2000).

Whale	Sub-pod	Tracks	Age
A13	A11	1	20
A33	A12	2	27
A39	A30	1	23
A46	A36	1	17
A6	A30	1	34
B10	B7	1	19
B2	B7	1	≥ 46
B8	B7	1	34
C9	C6	1	27
I41	I15	2	18

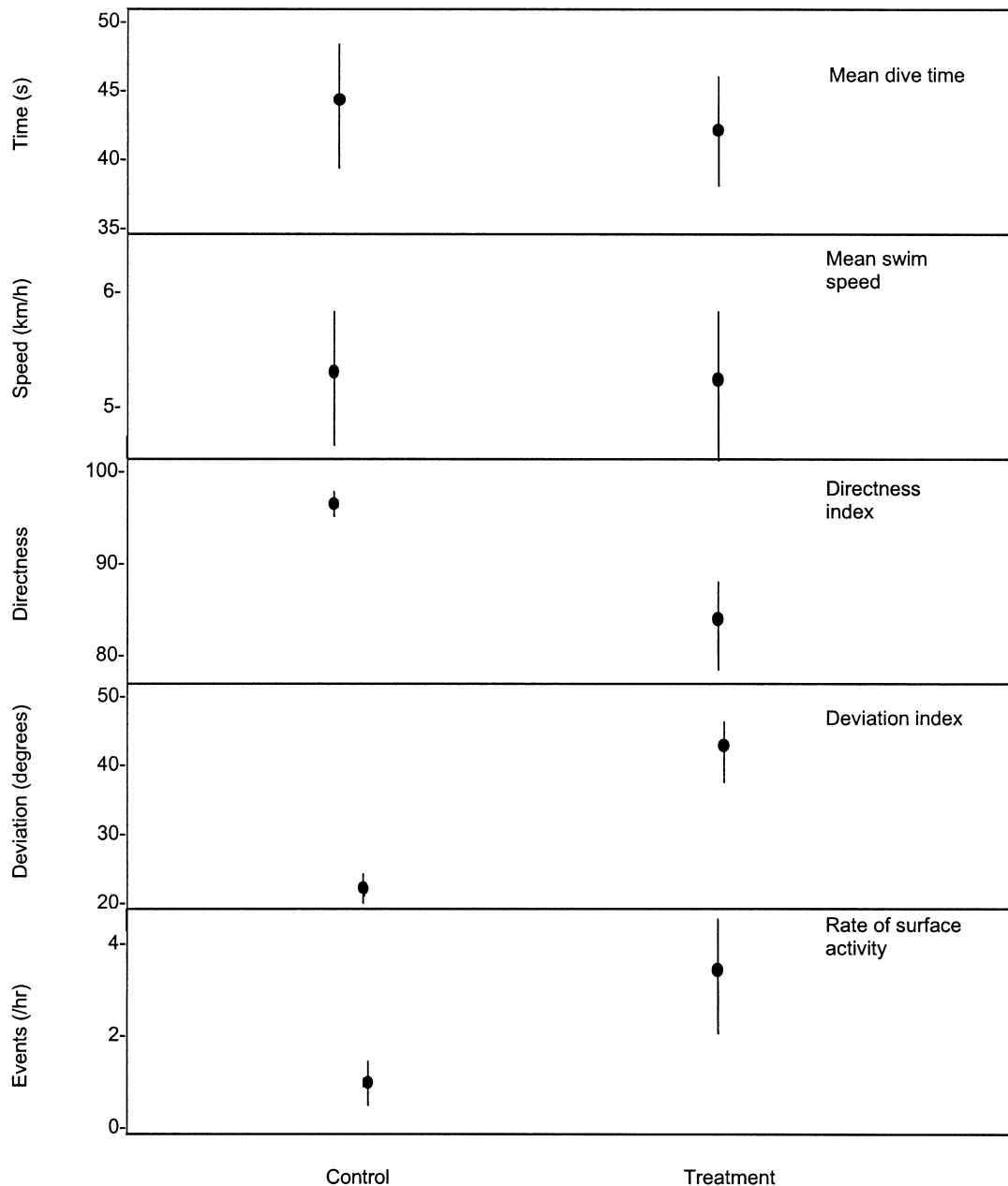


Fig. 3. Behavioural responses (mean ± SE) of whales to experimental approach by a leapfrogging vessel.

The mean speed of the experimental boat was measured during the leapfrogging sections of the theodolite tracks. On average, the experimental boat sped up to 20.7km/h (± 1.70 SE) during the leapfrog components of the 12 treatment tracks. The recordings made of the experimental boat during the high-speed approach are thought to accurately represent sound production during leapfrog approaches of whales: the mean speed of the boat did not differ significantly between samples ($t_{25} = -0.99, p = 0.330$).

Source level of the experimental boat at slow speed was estimated to be 148dB *re*: 1 μ Pa at 1m, assuming a spherical transmission loss model (Richardson *et al.*, 1995). When the experimental boat sped up to leapfrog, the source level increased to 162dB *re*: 1 μ Pa at 1m – an overall difference of +14dB. The greater sound pressure level under high speed was found across the entire frequency range of the on-board multi-channel recording equipment, and was observable to at least 24kHz (Fig. 4). The received levels were measured at 100m, and are presented in Fig. 4. At 200m, the distance at which the boat operator was instructed to leapfrog the whale's position, the received level was approximately 116dB.

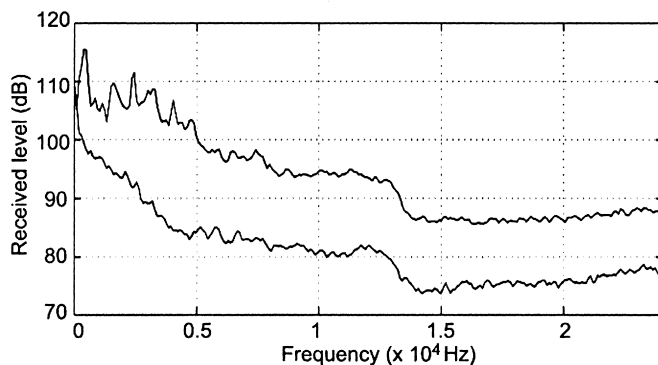


Fig. 4. Power spectral density comparing relative received noise level 100m from the experimental boat under fast (upper line) and slow (lower line) operating speeds.

If it is assumed that sound levels drop at $20\log_{10}(\text{range})$, a leapfrogging boat would need to be approximately 500m away from the whale for the level received by the whale to be the same as that from a boat paralleling at slow speed at 100m (Richardson *et al.*, 1995).

DISCUSSION

Northern resident killer whales evaded the leapfrogging vessel on two spatial scales (deviation and direction). Increased deviation index reflected a less predictable path on the scale of one surfacing to the next, while the reduced directness index reflected a less predictable path on the scale of an entire 20 minute observation session. These path predictability parameters were the same ones altered by a boat following whalewatching guidelines (Williams *et al.*, 2002), and therefore could be useful indices for assessing disturbance in northern resident killer whales.

There was a pronounced difference in the quality and level of sound produced by the experimental boat operating under two speeds. It is strongly recommended that whalewatching guidelines, in addition to limiting leapfrogging and proximity, also address speed of vessels around whales. In the absence of experimental studies to guide whalewatching activity by regulating noise level received by killer whales,

reducing boat speed is a useful proxy (Richardson *et al.*, 1995). More specifically, boaters should be discouraged from operating outboard engines at full speed within 500m of whales.

These findings are especially interesting in view of recent attempts to model zones of influence from boat noise (Erbe, 2002). The results in this paper are consistent with Erbe's prediction that a fast-moving boat would elicit change in behaviour of killer whales at 200-250m. Her prediction was based on the assumption that a 120dB received level would cause behavioural change in 50% of cetaceans (Richardson *et al.*, 1995). In fact, the current study demonstrated significant behavioural responses of male resident killer whales at received levels of approximately 116dB.

Effective management of whalewatching often requires choosing between practices that maximise human benefit and those that minimise disturbance to whales (Duffus and Dearden, 1993). The gain to whalewatchers from leapfrogging, where the benefit is a closer approach than that offered by other styles of whalewatching, may not be as high as one might assume. One study in Australia tested the assumption that whalewatchers wish to get close to whales (Orams, 2000), and found that tourist satisfaction was influenced by the number and behaviour of humpback whales, numbers of fellow passengers, cruise duration, boat construction and seasickness. However, proximity of the whales was not a major influence. The tendency in Johnstone Strait to discourage leapfrogging may be a case where mitigating disturbance to whales costs whalewatch operators very little in terms of tourist satisfaction.

Leapfrogging in close proximity to whales is a style of whalewatching engaged in mostly by the boating public, rather than by commercial operators in Johnstone Strait. Thus, the sample size in the present experiment was intended to test the null hypothesis that leapfrogging has no effect on behaviour. This sample was not intended to be large enough for the more stringent test of whether leapfrogging had more effect than paralleling, since this was not a particularly urgent management goal in Johnstone Strait, although it might be of interest to managers in other areas.

It is unfortunate that the experimental boat that elicited behavioural responses to a paralleling vessel at 100m in 1995 and 1996 (Williams *et al.*, 2002) is no longer available for acoustic monitoring. A concerted, experimental study to test both treatments simultaneously on the same subjects would be required. The members of the whalewatching and research communities of Johnstone Strait aim to endorse and follow biologically relevant whalewatching guidelines. It may be sufficient for their purposes to demonstrate that leapfrogging is disruptive. It is not necessary to illustrate that one whalewatching tactic is more disturbing to whales than another (given the same vessel and focal animals). Nonetheless, a qualitative comparison of whales' behavioural responses to the two types of whalewatching, paralleling and leapfrogging, may be instructive.

When a single vessel approached northern resident killer whales in 1995 and 1996 to parallel the animals at 100m, mean directness index of male killer whales declined from 83.6 to 74.1. A directness index of 83.6 is equivalent to having to travel 119.6m along a circuitous path to gain 100m of headway. The decline in directness index while a boat parallels at 100m is equivalent to having to travel 135m to cover the same distance – an increase of 13%. During leapfrogging tracks, mean directness index declined from 94.1 to 80.5, an increase of 17% in the distance a whale would have to swim to cover 100m of straight-line distance. More telling is the fact that no significant change was noted

in the deviation index, the mean angle between surfacings, when the experimental boat paralleled male whales' paths at 100m ($t_{23} = 0.56, p = 0.58$) (Williams *et al.*, 2002). When the experimental boat leapfrogged the swimming paths of the whales, the animals increased the mean angle between successive surfacings by 90%, from 20.4° to 38.7° (Fig. 3). A particularly noteworthy aspect of these findings was that significant effects were apparent even with small sample sizes.

Studies that measure short-term responses of animals to human disturbance often stem from an inability to tackle directly the underlying concern that repeated disturbance may have a cumulative impact on wildlife populations. Northern resident killer whales continue to return to Johnstone Strait each year after more than 20 years of whalewatching traffic and the population increased throughout this period (Ford *et al.*, 2000). Nevertheless, whalewatching has been cited as a likely contributing factor in recent population declines of southern resident killer whales (Baird, 2001).

Bain *et al.* (2002) produced a model for extrapolating energetic consequences, including those addressed in this study, to population-level effects. Studies employing methods similar to those here may be useful in quantifying the nature and magnitude of avoidance responses in order to estimate potential population-level costs of whalewatching across a range of traffic levels. More importantly, this work reveals an opportunity to mitigate some impact. By identifying a whalewatching practice that certainly carries energetic costs for killer whales and may reduce their foraging efficiency, it is hoped that members of the Johnstone Strait community continue to discourage that practice. Likewise, it is hoped that resource managers in other areas are encouraged by the Johnstone Strait model of establishing reasonable guidelines proactively, and then testing those guidelines experimentally to ensure biological relevance. Reducing short-term effects may ensure ultimately the mitigation of long-term consequences.

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Indications of habitat use patterns among small cetaceans in the central North Pacific based on fisheries observer data

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ABSTRACT

Biological specimens and environmental data collected by observers monitoring Japanese squid driftnet fishing operations during the summers of 1990 and 1991 in the central North Pacific (37°N-46°N, and 170°E-150°W) were used to explore habitat use patterns among three small cetacean species common to that area: the Dall's porpoise (*Phocoenoides dalli*), Pacific white-sided dolphin (*Lagenorhynchus obliquidens*) and northern right whale dolphin (*Lissodelphis borealis*). Sex and maturity status were determined for 805 northern right whale dolphins, 421 Pacific white-sided dolphins and 206 Dall's porpoises incidentally taken in 800 observed gillnet sets, allowing sub-taxon comparisons of habitat use patterns. Habitat variables were based on observer records of sea surface temperature (SST), wind velocity and direction, and swell height. Current velocity and direction and SST gradients were also derived. Canonical Correspondence Analysis (CCA) was used to relate the species categories to the habitat conditions recorded for the gillnet operations in which entanglements occurred. The samples collected from the southern, middle and northern latitudes within the overall study area were examined separately to account for northward movement of the fishing fleets across the summer months. SST was the most dominant and consistent feature; northern right whale dolphins occupied the warmest waters, Dall's porpoises the coldest; Pacific white-sided dolphins were found in-between, but more similar to the latter. Wind velocity and swell height also reflected potentially important habitat features. Young-of-the-year northern right whale dolphin showed a preference for the warmest waters observed in the middle latitude band, coincident with that species summer calving mode.

KEYWORDS: DALL'S PORPOISE; NORTHERN RIGHT WHALE DOLPHIN; PACIFIC WHITE-SIDED DOLPHIN; HABITAT; ECOSYSTEMS; BYCATCH; DISTRIBUTION

INTRODUCTION

The vast pelagic environment of the North Pacific provides habitat for a variety of often seen but infrequently studied porpoise and dolphin taxa. The three most common cetacean species in the central North Pacific (Hobbs and Jones, 1993), the northern right whale dolphin (*Lissodelphis borealis*), Pacific white-sided dolphin (*Lagenorhynchus obliquidens*) and Dall's porpoise (*Phocoenoides dalli*), share broadly overlapping distributions. The Dall's porpoise, principally a cold temperate and sub-arctic species of the North Pacific and adjacent seas, ranges from the Bering Sea south to 41°N in pelagic waters (Morejohn, 1979; Kasuya and Jones, 1984). The Pacific white-sided dolphin occurs across temperate Pacific waters, to latitudes as low or lower than 38°N, and northward to the Bering Sea (Leatherwood *et al.*, 1984; Walker *et al.*, 1984) and coastal areas of southeast Alaska (Dahlheim and Towell, 1994). The northern right whale dolphin is endemic to the North Pacific, ranging from approximately 30°N to 50°N in the eastern Pacific (Leatherwood and Walker, 1979) and 35°N to 51°N in the western Pacific (Sleptsov, 1961; Nishiwaki, 1967; Kasuya, 1971). Kajimura and Loughlin (1988) reported isolated sightings of northern right whale dolphins as far north as 52°N in the southwestern Aleutian Islands. Aside from descriptions of their relative distributions, little else is known about the relationships among these species and the characteristics of their physical and biological habitats.

Over the past three decades, opportunistic sightings surveys and research effort associated with high seas driftnet fisheries have provided platforms for several studies of life

history and population ecology for all three species (Buckland *et al.*, 1993; Ferrero and Walker, 1993; 1996; 1999; Hiramatsu, 1993; Miyashita, 1993; Tanaka, 1993; Turnock and Buckland, 1995; Turnock *et al.*, 1995). Movement patterns and stock structure of Dall's porpoises and Pacific white-sided dolphins have also been studied (Kasuya and Jones, 1984; Walker and Sinclair, 1990). Despite this, information on habitat use patterns for any of the three species is limited. Consequently, fundamental ecological questions remain unanswered, for example how do the distributions of these three species relate to habitat characteristics, and to what extent do they share or partition habitat? The objective of this paper, is to take an initial step toward answering these questions by using gillnet fisheries observer data to explore habitat use patterns. The relative levels of incidental take of these three species, across differing oceanographic and environmental conditions, provided the basis for comparisons.

Habitat partitioning studies often include diet as one of the dimensions reflecting differences among closely related species. Analyses of dietary data for these three species have not been completed but may eventually provide critical information on habitat partitioning. However, preliminary results suggest very little difference in diet (based on stomach contents analyses) of northern right whale and Pacific white-sided dolphins (Walker and Jones, 1993) while the prey of Dall's porpoises may differ slightly (Crawford, 1981; William A. Walker, pers. comm.). Likewise, anecdotal evidence from sightings data suggests that all three species can be found in proximity to one another and that northern right whale dolphins and Pacific white-sided dolphins are commonly observed in mixed schools

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(Leatherwood and Walker, 1979; Leatherwood *et al.*, 1982; 1984). Thus, most available information highlights the apparent similarities among the species rather than suggesting unique characteristics.

Empirical studies of species/habitat relationships have only recently been applied to marine mammals. Moore and DeMaster (1998) compared water depth and surface ice cover conditions associated with sightings of cetaceans in the Alaskan Arctic. Additional analyses of marine mammal habitat use patterns have employed the multivariate ordination technique known as Canonical Correspondence Analysis, CCA (see discussion in Ter Braak, 1986). Reilly and Fiedler (1994) applied CCA to sightings survey abundance data and oceanographic observations to compare habitat preferences among dolphin species in the Eastern Tropical Pacific. More recently, the same approach has been used to explore cetacean habitat partitioning in the California Current (Reilly *et al.*, 1997) and in the Western Tropical Indian Ocean (Ballance *et al.*, 1997).

Data reported here were collected in a broad segment of the North Pacific, ranging from approximately 150°W to 170°E and from 37° to 46°N. Oceanographic characteristics of the study area are summarised based on reviews of Uda (1963) and Dodimead *et al.* (1963). The primary habitat feature of the area is the Polar Front Region, located at approximately 45°N at 170°E and curving monotonically southward to approximately 42°N at 150°W. North of the Front, surface waters generally are of relatively low salinity (<33.0‰), with waters south of the front relatively more saline (>33.8‰). A significant feature of vertical structure north of the Front is a persistent halocline at depths of 80-150m. The halocline diminishes in intensity approaching the Front from the north, and is absent to the south. The latitudinal gradient in sea surface temperature (SST) across the Front is much stronger in the western than the eastern part of the study area. For example, at 175°E longitude, SST may increase from <10°C to >18°C over a north-to-south latitudinal interval of 4° during summer. At 155°W, summer SST may increase from <11°C to >20°C, but over a north-to-south latitudinal range of 10° or more. During summer, vertical temperature profiles north of the Front are dichothermal (*sensu* Uda, 1963). Temperature declines rapidly with depth to a temperature minimum of about 3°C at depths of 50-100m. Temperatures then rise to a secondary maximum of 5°C at approximately 120m, declining very slowly below that point with increasing depth. During winter months, SSTs decline by several degrees C, and mixing processes create isothermal and isohaline profiles in the upper 100m of the water column.

Surface circulation in the study area is dominated by the West Wind Drift north of the Polar Front and by the North Pacific Current to the south (Dodimead *et al.*, 1963). The two currents set in parallel from west to east, with waters in the North Pacific Current noticeably warmer than those in the West Wind Drift. In both cases flow velocity diminishes from west to east. At their respective western extremes, the West Wind Drift receives input from the relatively cold Oyashio Current, and the North Pacific Current from the relatively warm Kuroshio Current.

While this study shares a similar objective with other cetacean habitat preference studies, the method differs in two ways. First, rather than using sightings data to measure relative abundance, mortality data were used (incidental kills in high seas driftnets); appropriate sightings data are not available. Second, the results of life history investigations on each of the three marine mammal species (Ferrero and Walker, 1993; 1996; 1999) provided the means to

differentiate population components by sex and reproductive status, thus, allowing analysis of habitat use patterns both between and within species.

MATERIALS AND METHODS

Scientific observers stationed onboard Japanese squid driftnet vessels during 1990 and 1991 were trained to collect a standardised suite of data on each driftnet operation monitored (Fitzgerald *et al.*, 1993). The data elements included spatial and temporal reference points for the beginning and ending of net sets and net retrievals, the amount of gear fished, target species and bycatch tallies, and simple oceanographic and environmental measures: SST, wind velocity (Beaufort stage), wind direction and swell height.

Driftnet data from the three summer months of the fishing season when observer sampling was greatest were included in these analyses. From 1 June to 30 September, 1990 and 1991, 800 of the driftnet operations monitored in the central North Pacific (37°N to 46°N and 170°E to 150°W) resulted in the catches of northern right whale dolphin, Pacific white-sided dolphin or Dall's porpoise.

Biological data, including species identification, total length and sex, were collected from all marine mammals entangled and brought onboard dead. All entangled animals that were still alive when brought onboard, were released immediately and are not represented in this analysis. Note that observer records did not indicate a species, species group or size bias in the animals released alive. Life history specimens including reproductive organs were collected in cases where the observer had been appropriately trained and assigned marine mammal necropsy duties. Collection protocols, and laboratory examination of reproductive samples for determination of sexual maturity status followed procedures in Perrin *et al.* (1976) and Ferrero and Walker (1993).

The relative distribution and abundance of marine mammal species represented by driftnet catch composition were related to habitat conditions using CCA, specifically the routine contained in the computer program CANOCO version 3.1 (Ter Braak, 1988). CCA fits a unimodal response curve for each column in the species matrix to each of a set of orthogonal axes of the environmental matrix. The technique then seeks the set of orthogonal axes that minimise the width of the unimodal response. It should be noted that a monotonic response is a special case of the unimodal in which the mode is outside the domain of the environmental data so that only one side of the unimodal is fit and symmetry along each axis is a reasonable assumption to limit the number of variables to be fit. The model and algorithm documentation are detailed in Ter Braak (1988), while Reilly and Fiedler (1994) summarised the technique as applied to marine mammals. CCA extracts orthogonal axes of variation in indices of abundance for multiple species collected at multiple locations, with axes constrained to be linear combinations of measured environmental variables. The significance of the species category and environmental data relationship ($H_0: \lambda = 0$) reflected by the first canonical axis was tested using a Monte Carlo randomisation test (1,000 repetitions) incorporated in the CANOCO program.

The CANOCO program requires that data be organised into two matrices: one containing species abundances and the other containing environmental data. The matrices are linked by the sample units, which in this case were represented by each gillnet operation where at least one northern right whale dolphin, Pacific white-sided dolphin or

Dall's porpoise was caught. Differences in the amount of gear set per operation were compensated for by expressing all abundance measures as catch per unit effort (CPUE):

$$CPUE = (C_{x,y}/T_y) \times 1,000$$

where C_x is the total catch of species x in set y and T_y is the total number of tans of net fished in set y (a tan is equal to a 50m long by 12m deep panel of gillnet). Since each gillnet operation employed approximately 60km of gillnet, this distance set the lower limit on the scale of environmental features that could be described in the study.

Using the available life history information, both inter- and intraspecific species-environmental relationships were examined. For each of the three species, sex and sexual maturity status were incorporated by classifying each specimen into one of four groups (male or female \times sexually mature or immature). A 'young-of-the-year' category was added for northern right whale dolphins and Pacific white-sided dolphins which included only neonates and calves (<1 year old). Young-of-the-year Dall's porpoises were not encountered. Thus, a total of 14 categories were established.

Where reproductive organs had been collected, the results of laboratory examinations of gonadal tissues determined sub-taxa category assignment with respect to sexual maturity status. However, to maximise the sample, specimens were also classified that had not been necropsied, but for which species identification, length and sex were known. For these cases, species- and sex-specific estimates of average length at sexual maturity (LSM) were used as the grouping criteria. To reduce classification error, specimens with lengths within 5cm of LSM were not included, although less than 5% of all length measurements fell in this interval. Specimens larger than LSM were considered mature; those smaller were classified as immature. The LSM estimates for northern right whale dolphin, Pacific white-sided dolphin and Dall's porpoise were based on the life history investigations of Ferrero and Walker (1993), Ferrero and Walker (1996) and Ferrero and Walker (1999), respectively.

The data analysis was divided into three separate CCA runs using samples collected in the southern (37°N-40°N), middle (40°N-43°N) and northern (43°N-46°N) latitude

bands of the study area. The latitudinal stratification coincided with shifts in the fishing area occurring in response to regulatory openings or closings across the summer months (Nagao *et al.*, 1993). These shifts created almost entirely distinct fishing grounds as reflected by the location of sampling within the three bands (Fig. 1).

Ideally, the environmental variables included in CCA should reflect the most characteristic habitat features influencing community structure (Ter Braak, 1988). The best set of environmental variables to describe the small cetacean habitats in this study were unknown. The fishery observers' records, specific to each gillnet set monitored, were used to define values of the best available environmental parameters. These are discussed below.

Sea surface temperature (SST)

Sea surface temperature (SST) was recorded directly by observers from the ship's thermograph at the beginning and end of each retrieval operation. The mean SST value was used if readings were different. The sensors were generally located near the ship's keel, at a depth of about 3-4m. The range of observed SST was 11.0° to 18.8°C.

Delta SST

Delta sea surface temperature (DSST) was the difference in the temperature readings from one end of the net to the other. A large difference in SST across the 60km (maximum) net (e.g. >4.0°C) was considered an indication that the net crossed a thermal front. The DSST measurements ranged from 0.0-4.7°C.

Current velocity

The current velocity (CV) was calculated using the starting and ending times and positions of a chosen buoy marking a net end as:

$$CV = D/t_2 - t_1,$$

where t_1 is the time of buoy deployment and t_2 is the time of buoy retrieval.

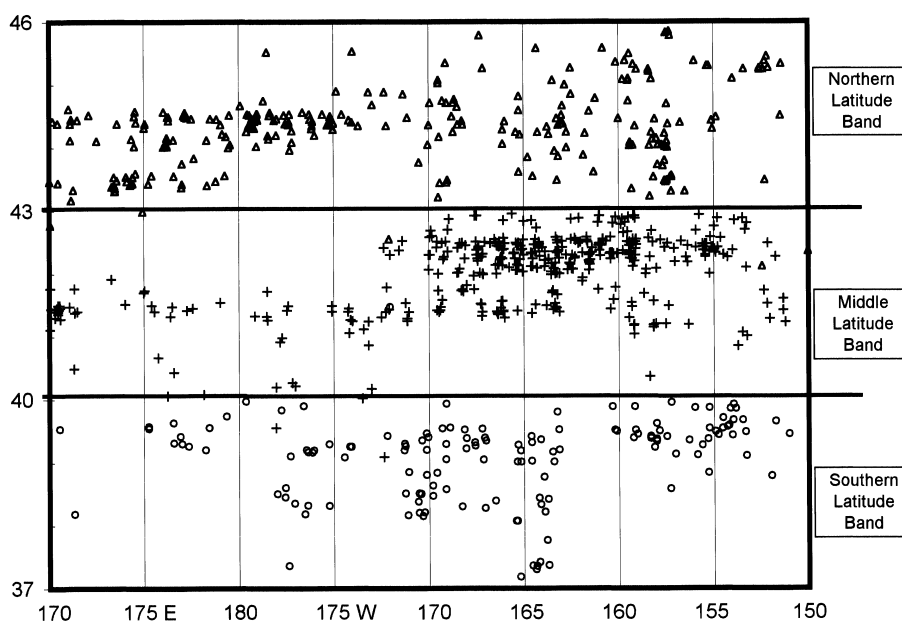


Fig. 1. Locations of Japanese driftnet fishing operations that resulted in one or more observed entanglements of Dall's porpoise (*Phocoenoides dalli*), Pacific white-sided dolphin (*Lagenorhynchus obliquidens*) or northern right whale dolphin (*Lissodelphis borealis*) during 1990 and 1991. The circles, crosses and triangles represent the sampling locations for the southern, middle and northern latitude data sets, respectively.

The distance travelled by the buoy (D) was calculated as:

$$D = (60 \times (180/\pi) \times \arccos(\sin lat_1) \times \sin lat_2) + (\cos lat_1 \times \cos lat_2 \times \cos(lon_2 - lon_1))$$

where lat_1 is the latitude of the initial position, lat_2 is the latitude of the ending position, lon_1 is the longitude of the initial position and lon_2 is the longitude of the ending position. The variables lat_1 , lat_2 and the term $(lon_2 - lon_1)$ are expressed in radians.

The drift of that particular buoy was assumed to represent the general velocity of the water mass containing the net. Current velocities up to 6.0 knots were calculated.

Current direction

Current direction was broken into two components (east/west and north/south) because the non-linear measurement from 0-359 degrees would represent a confounded gradient in the CCA (i.e. both ends of the scale, 0 and 359 degrees represented virtually the same wind direction). Instead, since the mean current direction in the study area was eastward, corresponding to the dominant flows of the West Wind Drift and the North Pacific Current (Dodimead *et al.*, 1963; Pickard and Emery, 1991), variations from this norm, suggesting possible eddies or counter-currents, were considered potentially important habitat features. The east/west aspect was calculated as the cosine of the angular direction. Strong deviation from an easterly flow would suggest a counter-current. The north/south aspect was characterised, without regard to direction, as the absolute value of the sine of angular direction. This approach assumed that currents flowing northward rated the same importance as currents flowing southward as habitat features.

Wind velocity

Wind velocity was recorded by observers using the Beaufort scale at the beginning of the net retrieval operation and up to four additional times thereafter. When conditions changed during the operation, an average value, rounded to the nearest whole number, was used. Higher wind velocities were considered indicative of local storm activity, which could give rise to greater surface mixing. Observed wind velocities ranged from Beaufort 0 (0-1kt, $<3\text{ms}^{-1}$) to Beaufort 7 (28-33kt, $13.9\text{-}17.1\text{ms}^{-1}$).

Wind direction

Wind direction was broken into north/south and east/west components following the same logic described for current direction. The prevailing winds in the study area were from the west, so that winds from the north, south or east deviating from the norm were considered possible stimuli for enhanced surface mixing. Like current direction, the east/west aspect was calculated as the cosine of the angular direction and the north/south aspect as the absolute value of the sine.

Swell height

Swell height was estimated directly by observers and recorded as distance from trough to crest. It provided an index to storm activity beyond the local area and up to several days earlier. Its local effect would have been an increase in surface mixing. Estimated swell heights ranged from 0-10m.

These definitions resulted in nine environmental parameters (including both the north/south and east/west aspects of parameters 4 and 6) that could be quantified and

included in the CCA analyses. Although several were considered potential causes of enhanced surface mixing and higher productivity levels, they were treated as separate parameters to explore possible differences in their relative importance.

Interpretation of CCA plots

For each of the three CCA analyses, a plot was generated to show the relative positions of species categories in ordination space as well as their relationships to the first two orthogonal axes and the environmental parameters. Each species category was given a different symbol and its eigenvalue plotted on Axis 1 and Axis 2. The environmental gradients were represented by vectors from the origin. In general, the longer the vector the greater of the variance represented by the eigenvalues that it could explain. Similarly, the eigenvalues most closely aligned with and farthest out along a particular vector, indicated the strongest relationship between the species and the habitat described by the environmental feature. The degree of similarity between species habitat selection patterns was described by ranges about each eigenvalue based on 'species tolerance values' calculated by CANOCO. These values represent the approximate measures of the species response curves along a particular ordination axis (Smilauer, 1992) and are analogous to the 95% confidence limits for the species loadings as used by Reilly and Fiedler (1994). In short, they define the area of the ordination around each species that reflects the habitat characteristics where that species was caught. Overlapping tolerance ranges, thus, indicate habitats shared by two or more species categories, while discrete tolerance ranges suggest occupation of different habitat types (i.e. habitat partitioning).

RESULTS

A total of 800 observed fishing operations resulted in catches of one or more of the three small cetacean species, including 143 sets in the southern, 384 in the middle and 273 in the northern latitude bands. These operations resulted in 1,432 incidental catches, comprising of 805 northern right whale dolphins, 421 Pacific white-sided dolphins and 206 Dall's porpoise (Table 1).

Across the three CCA runs, the gradient of SST was the most pronounced environmental feature underlying the placement of species categories, and was highly correlated with one of the first two orthogonal axes. Wind velocity (Beaufort scale) also appeared to be a relevant habitat feature. Wind velocity tended to be more strongly correlated with the first orthogonal axis if SST was correlated with the second axis, and vice versa. To a lesser degree (i.e. based on r -values), swell height and deviations in wind direction to the north or south of the predominant westerlies (i.e. wind N/S) were also relevant, and generally aligned with the gradient in wind velocity. Compared to these environmental parameters, those describing current velocity, current direction or differences in sea surface temperature across the length of a driftnet (DSST) were poorly correlated with either of the first two orthogonal axes and inconsistent in terms of their alignment with the other environmental parameters across latitude in the three CCA runs. Thus, the following descriptions of each ordination plot focus primarily on the relationships between the dominant environmental gradients and the species eigenvalues.

Table 1

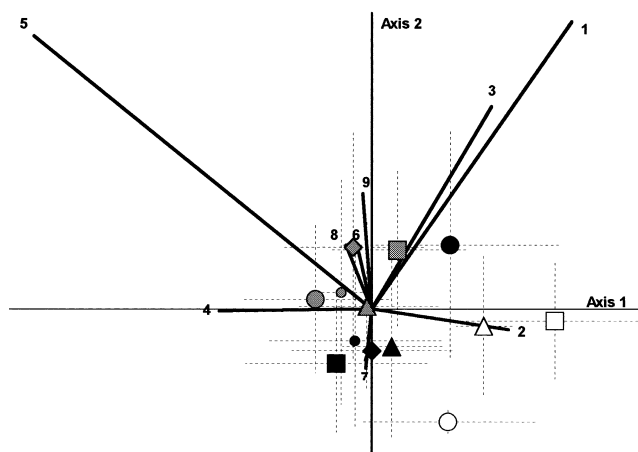
Numbers of marine mammals by species, category, latitude band included in each of the three CCA runs analysing dolphin and porpoise species relative abundance (as reflected by incidental catch data) and environmental data collected in high seas driftnets during June-August 1990 and 1991 in the central North Pacific Ocean.

Species	Latitude Band			Total
	Southern	Middle	Northern	
<i>L. borealis</i>				
Mature males	13	63	35	
Immature males	33	116	65	
Mature females	26	137	94	
Immature females	27	102	49	
Young-of-the-year	2	9	34	
Total	101	427	277	805
<i>L. obliquidens</i>				
Mature males	13	21	22	
Immature males	18	41	45	
Mature females	12	19	23	
Immature females	18	38	50	
Young-of-the-year	37	46	18	
Total	98	165	158	421
<i>P. dalli</i>				
Mature males	7	42	17	
Immature males	0	42	20	
Mature females	3	6	15	
Immature females	3	24	27	
Total	13	114	79	206
Grand total	212	706	514	1,432

The southern latitude band

A total of 143 fishing operations were sampled from 37°N to 40°N, and 170°E to 150°W, representing the southern extent of the fishing grounds typical of early summer (i.e. June) (Fig. 1). All species categories except immature male Dall's porpoises were represented in the sample. The percentage of variance explained by Axis 1 and Axis 2 was 31.5% and 22.1%, respectively (Table 2).

Axis 1 showed a strong negative correlation with SST ($r = -0.7452$) (Table 3). The mature male, immature female and mature female Dall's porpoises occupied positive Axis 1 eigenvalues, suggesting a preference for cooler waters (Fig. 2). Of these, the mature female Dall's porpoises occupied the most extreme position (i.e. coolest waters) along the SST gradient. The opposite side of the SST gradient, corresponding to warm waters, was populated by all categories of northern right whale dolphin. Pacific white-sided dolphins filled in between the other two species,



Species	Male		Female		Young-of-the-year
	Mature	Immature	Mature	Immature	
Dall's porpoise	◇	q	○	△	
Pacific white-sided dolphin	u	n	l	s	i
Northern right whale dolphin	u	n	l	s	i

Fig. 2. Species ordination diagram for CCA run 1, the southern latitude band (37°N to 40°N), relating species category occurrence along environmental gradients associated with the first two canonical axes. Species tolerance limits are represented by the dashed lines. Vectors representing each environmental vector are indicated by the solid dark lines and labelled as follows: (1) Beaufort wind velocity; (2) swell; (3) wind direction (N/S); (4) wind direction (E/W); (5) sea surface temperature; (6) delta sea surface temperature; (7) current velocity; (8) current direction (N/S); and (9) current direction (E/W).

suggesting a range of SST preferences that included both the upper extreme for Dall's porpoise and lower extreme for northern right whale dolphin.

Axis 2 was most strongly correlated with wind velocity ($r = 0.5815$). The north/south deviation in wind direction (wind N/S) was closely aligned with wind velocity, but its correlation with Axis 2 was less pronounced ($r = 0.4114$) (Table 3). Northern right whale dolphin eigenvalues were all positive. With the exception of mature females, all Pacific white-sided dolphin eigenvalues were negative.

The tolerance ranges for all species overlapped those of at least one other species category in all cases. The overlap was typically broad, indicating shared occupation of habitats

Table 2

Ordination results from CCA run 1, the southern latitude band (37°N to 40°N), for dolphin and porpoise species relative abundance (as reflected by incidental catch data) and environmental data (wind speed, swell height, wind direction, sea surface temperature, current velocity and current direction) collected on high seas gillnet vessels during June-August 1990 and 1991 in the central North Pacific Ocean. Species-Environmental Total (Sp-Env) is the total species variation related to the environmental variables. 'Total variation' represents all variation in the species incidental catch data. The P-values are based on a Monte Carlo randomisation test (1,000 repetitions).

	Canonical axes				Sp-Env total	Total variation
	1	2	3	4		
Eigenvalues	0.273	0.192	0.155	0.114	0.734	9.091
P-values	<0.001				<0.001	
Species-environment correlations	0.550	0.483	0.405	0.377		
Cumulative percentage variance						
Species-environment relation	31.5	53.6	71.5	84.7		
Total species data	3.0	5.1	6.8	8.1		

Table 3

Correlation matrix from CCA run 1, the southern latitude band (37°N to 40°N), for dolphin and porpoise species relative abundance (as reflected by incidental catch data) and environmental data collected on high seas gillnet vessels during June-August 1990 and 1991 in the central North Pacific Ocean.

	SPEC AX1	SPEC AX2	SPEC AX3	SPEC AX4	ENV AX1	ENV AX2	ENV AX3	ENV AX4	BEAU	SWELL	WIND N/S	WIND E/W	SST	DSST	CURR VEL	CURR N/S	CURR E/W
SPEC AX1	1.0000																
SPEC AX2	-0.0263	1.0000															
SPEC AX3	0.0426	-0.0503	1.0000														
SPEC AX4	0.0330	0.0287	0.0007	1.0000													
ENV AX1	0.5504	0.0000	0.0000	0.0001	1.0000												
ENV AX2	0.0000	0.4826	0.0000	0.0000	0.0000	1.0000											
ENV AX3	0.0000	0.0000	0.4053	0.0000	0.0000	0.0000	1.0000										
ENV AX4	0.0000	0.0000	0.0000	0.3766	0.0000	0.0000	0.0000	1.0000									
BEAU	0.2305	0.2806	-0.0791	0.1080	0.4188	0.5815	-0.1951	0.2867	1.0000								
SWELL	0.1651	-0.0203	-0.0828	0.1284	0.3000	-0.0420	-0.2043	0.3410	0.5628	1.0000							
WIND N/S	0.1447	0.1986	0.0820	-0.1216	0.2629	0.4114	0.2023	-0.3228	-0.1084	-0.1020	1.0000						
WIND E/W	-0.1843	-0.0018	-0.1688	0.1761	-0.3348	-0.0037	-0.4165	0.4678	-0.1543	-0.1430	-0.0397	1.0000					
SST	-0.4102	0.2677	-0.0365	-0.0358	-0.7452	0.5546	-0.0901	-0.0950	0.1171	-0.0039	0.0158	0.0832	1.0000				
DSST	-0.0154	0.0559	0.0138	0.0788	-0.0281	0.1159	0.0339	0.2093	-0.1129	-0.1035	0.1813	-0.0672	-0.0437	1.0000			
CURR VEL	-0.0069	-0.0575	0.3502	0.0802	-0.0126	-0.1192	0.8640	0.2129	-0.0650	-0.1036	0.0132	-0.1177	-0.1884	-0.1092	1.0000		
CURR N/S	-0.0258	0.0634	0.0424	0.1920	-0.0469	0.1314	0.1045	0.5099	-0.0629	-0.0884	0.1217	0.1749	0.0976	0.0853	0.0098	1.0000	
CURR E/W	-0.0108	0.1133	0.0072	0.0762	-0.0197	0.2347	0.0177	0.2022	0.0483	0.0459	-0.1111	0.0638	0.1024	0.0691	-0.2186	-0.0180	1.0000

Table 4

Correlation matrix from CCA run 2, the middle latitude band (40°N to 43°N), for dolphin and porpoise species relative abundance (as reflected by incidental catch data) and environmental data collected on high seas gillnet vessels during June-August 1990 and 1991 in the central North Pacific Ocean.

	SPEC AX1	SPEC AX2	SPEC AX3	SPEC AX4	ENV AX1	ENV AX2	ENV AX3	ENV AX4	BEAU	SWELL	WIND N/S	WIND E/W	SST	DSST	CURR VEL	CURR N/S	CURR E/W
SPEC AX1	1.0000																
SPEC AX2	-0.0108	1.0000															
SPEC AX3	-0.0400	-0.0174	1.0000														
SPEC AX4	0.0103	-0.0478	-0.0504	1.0000													
ENV AX1	0.5354	0.0000	0.0000	0.0000	1.0000												
ENV AX2	0.0000	0.2792	0.0000	0.0000	0.0000	1.0000											
ENV AX3	0.0000	0.0000	0.2537	0.0000	0.0000	0.0000	1.0000										
ENV AX4	0.0000	0.0000	0.0000	0.2194	0.0000	0.0000	0.0000	1.0000									
BEAU	0.0908	0.1625	-0.0416	0.0946	0.1696	0.5821	-0.1641	0.4313	1.0000								
SWELL	0.0680	0.1558	0.0004	0.0548	0.1271	0.5581	0.0016	0.2496	0.5344	1.0000							
WIND N/S	-0.0157	-0.1388	-0.1532	0.0729	-0.0294	-0.4969	-0.6039	0.3322	-0.0802	0.0504	1.0000						
WIND E/W	0.0506	-0.0866	0.1118	0.0108	0.0945	-0.3100	0.4405	0.0492	-0.1733	-0.2281	-0.0930	1.0000					
SST	-0.5133	0.0477	-0.0173	-0.0168	-0.9588	0.1709	-0.0680	-0.0767	-0.0805	-0.0344	0.0126	-0.2055	1.0000				
DSST	-0.0114	0.0836	-0.0223	0.0826	-0.0213	0.2995	-0.0879	0.3764	-0.1107	-0.0196	-0.0074	0.0235	-0.0269	1.0000			
CURR VEL	-0.0726	-0.0360	-0.0036	-0.0772	-0.1335	-0.1291	-0.0141	-0.3516	-0.0572	-0.0583	0.0765	0.0793	0.0382	-0.0487	1.0000		
CURR N/S	0.1498	0.0285	0.0808	-0.0226	0.2798	0.1019	0.3185	-0.1031	-0.0939	-0.0186	0.0415	0.1650	-0.1327	0.0354	-0.0255	1.0000	
CURR E/W	0.1051	0.1111	-0.1110	-0.1359	0.1963	0.3977	-0.4374	-0.6193	0.0369	-0.1062	-0.2400	-0.0411	-0.0309	-0.0199	-0.0849	0.0350	1.0000

despite the general tendencies noted above. However, each of the three Dall's porpoise categories tolerance ranges were completely separate from two or more northern right whale dolphin species categories on the opposite side of the SST gradient. The mature categories of Dall's porpoise were the most isolated, with no habitat characteristics in common with the mature or neonatal categories of northern right whale dolphin. In addition, the mature female Dall's porpoises were completely partitioned from all other categories along Axis 2, suggesting they were sampled in calmer sea conditions (i.e. where low wind velocities were recorded) in areas with prevailing westerly winds.

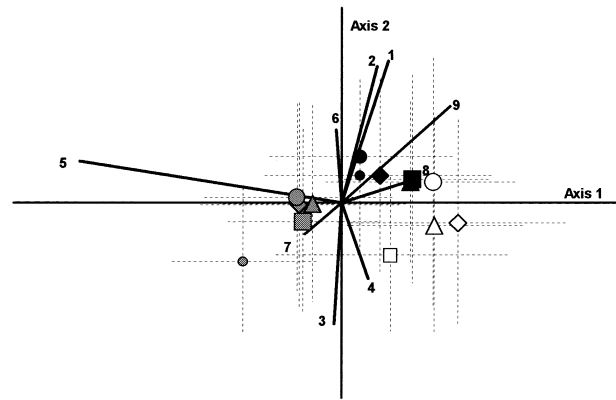
The middle latitude band

The fishery moved northward in July to a band extending from 41°N to 43°N east of 170°W and from 41°N to 42°N west of 170°W (Fig. 1). Of the 384 operations sampled, only six occurred in areas fished the previous month. All 14 species categories were present. The first and second canonical axes explained 46.7% and 13.8% of the variance in the species-environment relation (Table 5).

As in the southern latitude band (Fig. 2), the dominant environmental gradient in the second run was SST, negatively correlated with Axis 1 ($r = -0.9588$) (Fig. 3, Table 4). The juxtaposition of species categories along the SST gradient was also consistent with the results from the southern latitude band, with Dall's porpoise occupying the coolest waters, northern right whale dolphins in the warmest waters and Pacific white-sided dolphins in-between.

The proximity of Dall's porpoise and Pacific white-sided dolphin species categories, all of which scored positive eigenvalues for both canonical axes 1 and 2, were more pronounced than in the previous run, again indicating a tendency toward occupation of similar habitats. Conversely, the northern right whale dolphin species categories were more isolated, particularly along Axis 1 (correlated with the SST gradient). The neonate northern right whale dolphin category occupied the most extreme position on the SST gradient, in the warmest waters encountered in the middle latitude band. In regard to species tolerance ranges, overlap was evident among most species except in the case of the neonate northern right whale dolphin. In its extreme position on the 'warm side' of the SST gradient, this category shared no habitat characteristics with three of the four Dall's porpoise categories (immature males and females and mature females).

Axis 2 was positively correlated with wind velocity ($r = 0.5821$) and swell height ($r = 0.5581$). Conversely, Axis 2 was negatively correlated with wind N/S direction



Species	Male		Female		Young-of-the-year
	Mature	Immature	Mature	Immature	
Dall's porpoise	◇	q	○	△	
Pacific white-sided dolphin	u	n	l	s	l
Northern right whale dolphin	u	n	l	s	l

Fig. 3. Species ordination diagram for CCA run 2, the middle latitude band (40°N to 43°N), relating species category occurrence along environmental gradients associated with the first two canonical axes. Species tolerance limits and environmental vectors are indicated as in Fig. 2.

($r = -0.4969$) (Table 4). Taken together, these correlations suggest that high positive values along Axis 2 represent rougher sea conditions with winds deviating from the dominant westerly pattern. The Pacific white-sided dolphin categories, for instance, appeared to occupy areas with slightly more extreme sea conditions, although their tolerance ranges overlapped those of nearly all other categories. Most notably, however, was the location of the neonate northern right whale dolphin category, oriented toward the 'calmer' side of the sea condition gradient coincident with Axis 2.

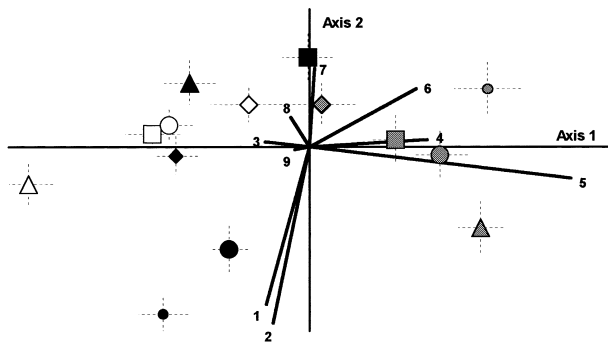
The northern latitude band

The fishery reached its northern limit in August, extending nearly to 46°N east of 170°W, and to 45°N west of 170°W (Fig. 1). Only three of the 273 operations in this sample occurred in the area represented in the middle latitude band. All 14 species categories were contained in the sample.

Table 5

Ordination results from CCA run 2, the middle latitude band (40°N to 43°N), for dolphin and porpoise species relative abundance (as reflected by incidental catch data) and environmental data (wind speed, swell height, wind direction, sea surface temperature, current velocity and current direction) collected on high seas gillnet vessels during June-August 1990 and 1991 in the central North Pacific Ocean. Species-Environmental Total (Sp-Env) is the total species variation related to the environmental variables. 'Total variation' represents all variation in the species incidental catch data. The *P*-values are based on a Monte Carlo randomisation test (1,000 repetitions).

	Canonical axes				Sp-Env total	Total variation
	1	2	3	4		
Eigenvalues	0.238	0.054	0.038	0.028	0.358	8.760
P-values	<0.001				<0.001	
Species-environment correlations	0.535	0.279	0.254	0.219		
Cumulative percentage variance						
Species-environment relation	60.5	74.3	83.8	91.0		
Total species data	2.7	3.3	3.8	4.1		



Species	Male		Female		Young-of-the-year
	Mature	Immature	Mature	Immature	
Dall's porpoise	◇	q	○	△	
Pacific white-sided dolphin	u	n	l	s	i
Northern right whale dolphin	u	n	l	s	i

Fig. 4. Species ordination diagram for CCA run 3, the northern latitude band (43°N to 46°N), relating species category occurrence along environmental gradients associated with the first two canonical axes. Species tolerance limits and environmental vectors are indicated as in Fig. 2.

The first two canonical axes explained 49.4% and 15.9% of the variance in the species-environment relation (Fig. 4, Table 6). Axis 1 was highly correlated with positive values of SST ($r=0.8679$) (Table 7). Once again, all categories of northern right whale dolphin were located in areas corresponding to higher water temperatures along the SST gradient. The Dall's porpoise categories were located on the 'lower temperature' side of the SST gradient similar to the pattern seen in the two previous areas. However, unlike in the two previous areas, two of the Pacific white-sided dolphin categories were interspersed with those of the Dall's porpoise (immature male and mature female).

Axis 2 was negatively correlated with swell height ($r=-0.7666$) and wind velocity ($r=-0.6845$) and positively correlated with current velocity. Along Axis 2, neonatal and mature female Pacific white-sided dolphins again occupied the most extreme locations representing the highest wind velocity and swell conditions observed in the northern band of the study area.

Unlike in either of the previous areas (Figs 2 and 3), the tolerance ranges around nearly all species categories were small, with no overlap between those ranges in all cases

except for one cluster containing mature male and female Dall's porpoises and immature male Pacific white-sided dolphins.

DISCUSSION

Canonical Correspondence Analysis offered substantial power to reduce the dimensions of a large multivariate dataset with direct application to habitat relationships in the marine environment. It was recognised that caution has been expressed in the application of CCA to 'noisy' datasets because it can produce distorted images of community structure (McCune, 1997). It is believed that the results in this study are robust to those concerns for two reasons. First, the objective related only to the description of species responses to observed environmental variables which McCune (1997) identifies as an appropriate use of CCA. Second, interpretation of the ordinations was constrained to only broadest observed relationships between the species categories and the dominant environmental variables.

Even so, in preliminary CCA runs it was noted that the results were sensitive to the inclusion of certain data, particularly date and latitude. Preliminary CCA runs including those variables produced uninformative results, driven by the fact that management regulations had established a northward movement of fishing across the summer. The location of species categories simply reflected the relative numbers of each species caught over that time/space gradient, not the underlying environmental conditions. Hence, the decision to stratify by latitude and perform three separate analyses.

The mortality data compared favourably to studies based on marine mammal sightings as a means of explaining variance in species-environmental relationships (e.g. Reilly and Fiedler, 1994). The technique, therefore, may be useful where either of these two common sources of marine mammal distributional data (mortality or sightings data) are available, so long as the mortality data reflects the relative abundance of subject animals in the study area (Ferrero and Walker, 1993). However, the collection of concurrent data on habitat features should be improved beyond those used in this study when possible, particularly with respect to the range of oceanographic and environmental variables considered.

Although the driftnet fisheries data available for the multivariate analyses lacked the detail necessary to describe oceanographic habitats in specific technical terms, they were sufficient to represent contrasts in environmental conditions and provide a basis for detecting habitat selection patterns.

Table 6

Ordination results from CCA run 3, the northern latitude band (43°N to 46°N), for dolphin and porpoise species relative abundance (as reflected by incidental catch data) and environmental data (wind speed, swell height, wind direction, sea surface temperature, current velocity and current direction) collected on high seas gillnet vessels during June-August 1990 and 1991 in the central North Pacific Ocean. Species - Environmental Total (Sp-Env) is the total species variation related to the environmental variables. 'Total variation' represents all variation in the species incidental catch data. The *P*-values are based on a Monte Carlo randomisation test (1,000 repetitions).

	Canonical axes				Sp-Env total	Total variation
	1	2	3	4		
Eigenvalues	0.202	0.065	0.055	0.033	0.355	7.881
P-values	<0.001				<0.001	
Species-environment correlations	0.504	0.342	0.297	0.226		
Cumulative percentage variance						
Species-environment relation	49.4	65.3	78.7	86.8		
Total species data	2.6	3.4	4.1	4.5		

Table 7
 Correlation matrix from CCA run 3, the northern latitude band (43°N to 46°N), for dolphin and porpoise species relative abundance (as reflected by incidental catch data) and environmental data collected on high seas gillnet vessels during June-August 1990 and 1991 in the central North Pacific Ocean.

	SPEC AX1	SPEC AX2	SPEC AX3	SPEC AX4	ENV AX1	ENV AX2	ENV AX3	ENV AX4	BEAU	SWELL	WIND N/S	WIND E/W	SST	DSST	CURR VEL	CURR N/S	CURR E/W
SPEC AX1	1.0000																
SPEC AX2	0.0265	1.0000															
SPEC AX3	-0.0323	-0.0298	1.0000														
SPEC AX4	0.0320	0.0235	-0.0892	1.0000													
ENV AX1	0.5043	0.0000	0.0000	0.0000	1.0000												
ENV AX2	0.0000	0.3419	0.0000	0.0000	0.0000	1.0000											
ENV AX3	0.0000	0.0000	0.2968	0.0000	0.0000	0.0000	1.0000										
ENV AX4	0.0000	0.0000	0.0000	0.2259	0.0000	0.0000	0.0000	1.0000									
BEAU	-0.0724	-0.2340	0.0917	0.0438	-0.1178	-0.7666	0.1942	0.1942	1.0000								
SWELL	-0.0594	-0.2621	-0.0520	0.0642	-0.1178	-0.7666	0.1942	0.1942	0.5737	1.0000							
WIND N/S	-0.0732	0.0067	-0.1832	0.0063	-0.1451	0.0195	0.0279	0.0279	0.0377	-0.0570	1.0000						
WIND E/W	0.1965	0.0100	0.0079	-0.1498	0.3897	0.0294	-0.6631	-0.6631	-0.2322	-0.2568	-0.1052	1.0000					
SST	0.4376	-0.0469	-0.0430	0.0436	0.8679	-0.1371	0.1930	0.1930	-0.0257	-0.0391	-0.1309	0.1425	1.0000				
DSST	0.1792	0.0868	0.0364	-0.0452	0.3554	0.2238	-0.2004	-0.2004	-0.0612	0.0009	-0.0615	0.0778	0.0547	1.0000			
CURR VEL	0.0090	0.1167	0.0156	0.1198	0.0179	0.3415	0.0526	0.5303	0.1370	0.0479	-0.0740	-0.0070	0.0105	-0.0174	1.0000		
CURR N/S	-0.0308	0.0443	-0.1223	-0.1057	-0.0611	0.1297	-0.4120	-0.4678	-0.1621	-0.1628	-0.0798	0.0237	0.1558	-0.0734	-0.0402	1.0000	
CURR E/W	-0.0230	-0.0042	0.0609	0.0666	-0.0455	-0.0123	0.2051	0.2948	0.0844	0.0018	-0.2323	-0.0809	0.1423	0.0900	0.0294	0.0294	1.0000

Differences in habitat selection preferences were suggested both between species and among species constituents. Not surprisingly, the most influential environmental gradient reflected in inter-species placement in ordination space was SST. Yatsu *et al.* (1993) reported temperature related differences in catch per unit effort among several fish and cephalopods caught in the Japanese squid driftnet fishery. Likewise, efforts to model the North Pacific transition zone and identify associations among taxa (MBC Applied Environmental Sciences) incorporated stratification by temperature.

Environmental variables other than SST were included as possible indicators of meso-scale habitat features, namely fronts (DSST), eddies (current velocity and direction) and atmospherically induced areas of increased surface mixing. The importance of either fronts or eddies using the indicators appeared to be low, explaining little of the variance in the species-environment relation. In contrast, consistent correlations between both wind velocity and swell height with Axis 2 were apparent. While this suggests that local mixing of surface waters may be an important habitat feature, it is noted that the ability to characterise other complex features like fronts and eddies was probably very low, and that they may still represent important features. Furthermore, since nearly all driftnet sets were oriented east/west, the analyses suffered a low probability of detecting latitudinal temperature gradients. For the purposes of these exploratory analyses, therefore, SST and surface layer mixing, regardless of their cause, are suggested to be among the habitat features of relevance to small cetaceans in the area studied.

Comparing the results of the three CCA runs, some patterns were consistent, while others were more ephemeral. Clearly, the most robust pattern related to SST preference. Northern right whale dolphins consistently occupied the warm water extremes, while fidelity to cooler waters was characteristic of Dall's porpoise. Pacific white-sided dolphin SST preferences were the broadest of the three species, although they were more allied with those of Dall's porpoise than northern right whale dolphin.

In the southern latitude band, Dall's porpoise were present only in low numbers, well separated from the other species categories in the ordination plots. This portion of the study area may have simply represented the southern fringe of Dall's porpoise habitat, but it was within the core range of the other two species. As the fishery advanced northward in succeeding months, the separation of the Dall's porpoise categories disappeared, and greater isolation of northern right whale dolphin categories took its place. This may have reflected the more southerly distribution of northern right whale dolphin and its more pronounced selection of warmer water habitats at higher latitudes near the fringes of its range.

In addition, northern right whale dolphin habitat preferences may relate to their reproductive activity at the time of sampling. Ferrero and Walker (1993) described a distinct calving mode for the northern right whale dolphin in June and July, in areas corresponding to the southern and middle portions of the study area. Neither of the other two species showed any indications of parturition at that time, in those areas. The northern right whale dolphin neonatal component was well separated from the other species categories in the southern latitude band ordination and positioned in the warmest and perhaps calmest waters. Failure of the northern right whale dolphin mature female category to mirror the same pattern may be an artefact of the sample categorisation process which only reflected sexual

maturity, not reproductive activity. Since northern right whale dolphins are not annual breeders (Ferrero and Walker, 1993), the mature female category contains both reproductively active and inactive individuals, of which the latter may not express the same habitat preferences as parturient females and calves. The reproductively active northern right whale dolphin females may, therefore, select habitats in summer that are specific to calving.

A marked contrast among the three CCA runs was in the lack of overlap between species tolerance ranges in the northern latitude band. One possible explanation for the difference may relate to the location of sampling and the diversity of habitats available for selection in those locations. At the southern and middle latitudes, sampling occurred in the North Pacific transition zone, south of the Polar Front Region (Uda, 1963; Pearcy, 1991; Roden, 1991). By comparison, in the northern latitude run, the fishery was probably positioned in the sub-arctic water mass, where habitats, described by combinations of environmental parameters, were more varied. It is unknown, however, whether the lower incidence of tolerance ranges there reflected more focused selection of habitats or an artefact of having more possible combinations of habitat types available, over which to distribute the species data.

These data are potentially useful in the context of conservation and management for the subject species. In addition, this approach may be applicable to evaluations of habitat preferences in other poorly known pelagic odontocetes, thereby contributing to conservation and management insights in the latter cases as well. Habitat characteristics define the ultimate potential distribution of a species, providing the basis against which the present numbers or range of any species or stock can be compared and allowing conclusions about conservation status of the species or stock. Quantitatively documented relationships of species and habitat permit meaningful predictions of trends in stock size or distribution in response to observed trends in physical habitat characters. It follows that observed changes in habitat quality can be interpreted with regard to conservation consequences for resident stocks. Similarly, spatial variation in habitat characteristics, within the extremes of tolerance for resident stocks, are of value in understanding within-species spatial variance in stock structure, with obvious benefit to conservation and management concerns. Obtaining good information on relationships of marine mammal species and habitat characteristics in the pelagic realm will remain logistically challenging and highly costly for the foreseeable future. Utilisation of unorthodox opportunities for data acquisition, such as this paper, will remain important for understanding habitat use in marine mammals as long as challenges and costs of pelagic research remain high.

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A note on vessel of opportunity sighting surveys for cetaceans in the shelf edge region off the southern coast of Brazil

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ABSTRACT

Results are presented from vessel of opportunity sighting surveys conducted from 1996 to 1999 aboard the Fundação Universidade Federal do Rio Grande (FURG) Research Vessel *Atlântico Sul* off the southern Brazil coast (27°-35°S). These surveys were conducted in conjunction with a research sampling project (Argo) of the pelagic living resources within Brazil's southern shelf and slope waters. The cruises entailed pelagic longlining and dedicated searching was conducted during hauling and setting operations as well as when the vessel was transiting. The sighting surveys represent the first attempt to collect quantitative information on the distribution and density of cetaceans in these waters. A total of 109 cetacean sightings were made during a total of 269 hours of dedicated searching effort covering approximately 2,200 miles. Sperm whales were the dominant species accounting for over 40% of the sightings and were concentrated in the slope area in the more southerly region. The high number and fidelity of the sperm whale sightings suggest the year around importance of the shelf border as a possible migration route and/or food resources ground. Killer whales were the second most commonly sighted species and were detected on all of the cruises. 44% of the killer whale sightings were detected during longline hauling or setting operations and observations suggest a positive attraction of killer whales to the vessel at these times. Also of particular interest during the spring cruise was a humpback and two minke whale sightings. Sightings in November-December in sub-tropical and temperate waters were unexpected for both of these species as the South Atlantic populations are generally considered to have fully migrated to Antarctic waters.

KEYWORDS: SOUTH AMERICA; SURVEY-VESSEL; SPERM WHALE; KILLER WHALE, DISTRIBUTION

INTRODUCTION

The coast and shelf waters of Brazil are known to contain a rich and wide diversity of marine mammals (Pinedo *et al.*, 1992; Pinedo, 1994) and a few specific areas are well known to be critical habitats for individual species (e.g. the right whale breeding areas, Best *et al.*, 1993; de Oliveira Santos *et al.*, 2001). However, there has been little or no systematic survey efforts for marine mammals in most areas and little is known about the relative importance of different habitats or seasonal patterns of utilisation, particularly in the more offshore waters. The southern shelf region of Brazil, from Rio Grande do Sul to Santa Catarina, is an area of complex and dynamic currents with areas of significant up-welling and high productivity, particularly in the most southern portion (Garcia, 1997; Odebrecht and Garcia, 1997).

In 1996, the research project Argo of the Oceanography Department at the Fundação Universidade Federal do Rio Grande (FURG) was initiated with the aim of increasing the knowledge of the pelagic living resources within the Exclusive Economic Zone (EEZ) of southern Brazil (from 26°17'S to 33°45'S). The continental shelf in southern Brazil is broad with the 200m depth contour generally 60 miles or more offshore. The Argo project's primary focus was to sample the stocks of larger pelagic fishes in the outer shelf and continental slope regions using pelagic longline gear. Sampling was conducted in three seasons over a four-year period using the FURG Research Vessel *Atlântico Sul*. In conjunction with the Argo project, the vessel was used as a sighting platform of opportunity for marine mammals as the project offered a unique opportunity to obtain extensive sighting coverage in the outer shelf region. These cruises represented the first attempt to collect quantitative information on the species composition,

distribution and density of cetaceans in the outer shelf region of southern Brazil. This paper presents the results obtained on cetaceans from the Argo cruises.

METHODS

Four cruises were undertaken during spring, summer and winter by the FURG Research Vessel *Atlântico Sul* (Fig. 1). Sightings data were collected on the two legs of the spring cruise (11-20 November 1996 and 27 November to 11 December 1996); on two winter cruises (1997: 5-12 July and 16-30 July and 1999 (5-20 August) and a single leg of a summer cruise (5-16 March 1998). Dedicated searching for cetaceans was conducted during all cruises by a single team of two observers searching simultaneously from the crew's nest at a height of 12m above sea level. Four individuals (A.S. Barreto, M.P. Lammardo, M.C. Pinedo and T. Polachek) participated as the observers during the course of the project, with the actual teams varying among the legs and seasons. There was always an overlap in the observer teams to ensure the continuity of the data collection procedures. Searching was usually conducted for periods of 1.5hrs, followed by a 0.5hr break.

Standard line transect information was collected for all cetacean sightings including data on the location, species identity, group size, radial distance and sighting angle. Information collected on environmental conditions included sea state (Beaufort), relative glare, weather and visibility conditions. Sighting angles were estimated using an angle board and radial sighting distances were estimated visually. To improve and calibrate their estimates, observers used buoys towed at measured distances (up to 400m) behind the vessel and objects at known distances.

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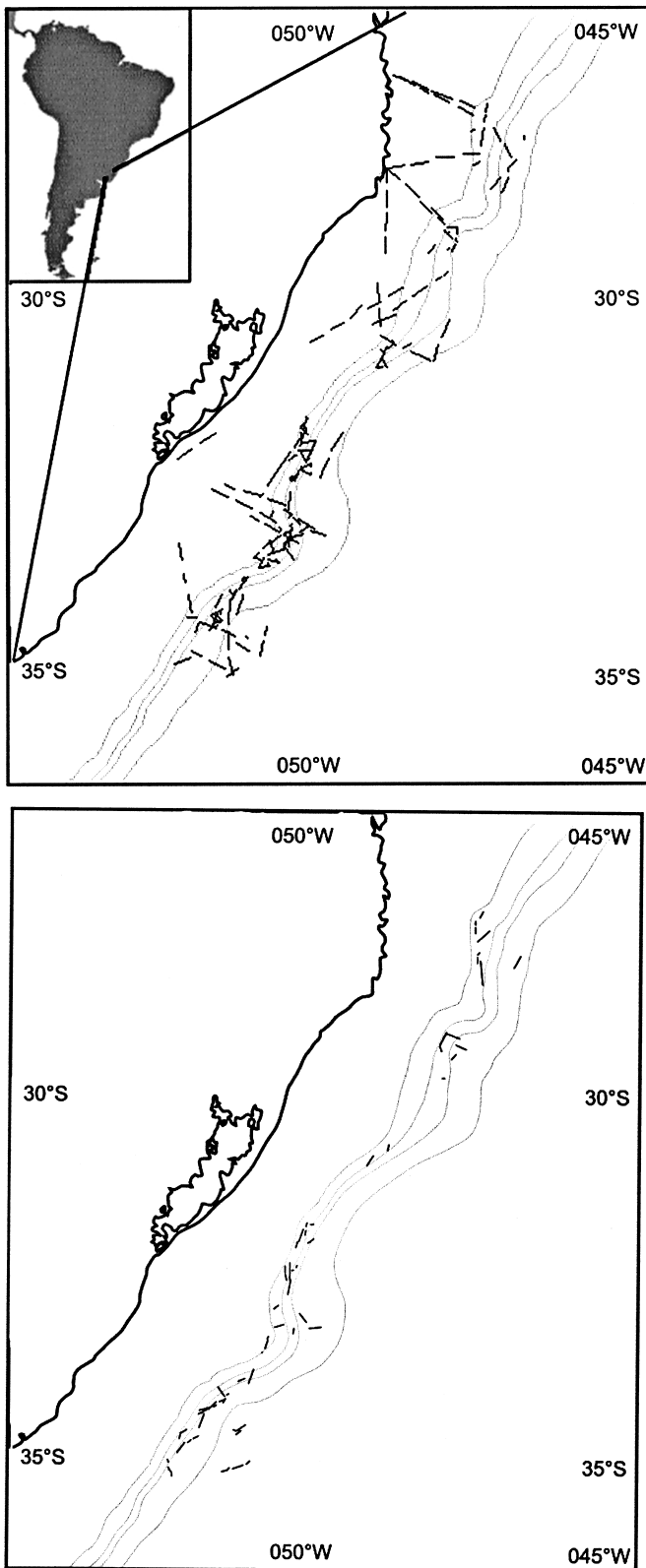


Fig. 1. The location of dedicated effort during the Argo cruises: (a) during transiting; and (b) during longline operations. Isobars are in meters, from left to right: 200, 600, 1,000, 2,000.

Dedicated searching was conducted during all periods of suitable sightings conditions (visibility > 1 n.mile, sea state < 5) when (1) the vessel was transiting (speeds 8-12 knots) during daylight hours, (2) the longline gear was being set (usually 4-8 knots) and (3) experimentally during the spring cruises when the longline gear was being hauled (usually 1-4 knots). The small amount of effort undertaken at sea states

≥ 5 was not included in the quantitative results. Searching was carried out with the naked eye. Binoculars were used to confirm possible sightings and to help with species identification. All surveying was carried out in passing mode (i.e. the vessel did not leave its predetermined course to confirm species identity or school size estimates).

Although the Argo project did not allow for a dedicated sighting survey design, attempts were made after the first cruise to better coordinate transit times between sampling stations and other non-research periods. This allowed for increased spatial coverage and greater amounts of searching time during daylight hours. It also improved the cross-shelf coverage of the area. This was achieved by: (1) setting up additional triangular searching transects when sighting conditions were suitable during drifting periods (e.g. when the longline gear was soaking – these were conducted at speeds and under conditions similar to transit legs); (2) having the long transit legs at the beginning and end of the cruises occur along the shelf region; and (3) scheduling transit legs between stations during daylight hours to the extent possible.

RESULTS

The cruises allowed for reasonable latitudinal coverage along the entire shelf area (Fig. 1); most of the larger gaps were due to sustained periods of unsuitable sighting conditions. All of the effort during longline operations occurred near the shelf edge, while the effort when the vessel was transiting also included more inshore waters (Fig. 1a, b). A summary of sighting effort and sightings per unit effort by season and vessel activity is given in Table 1.

A total of 109 cetacean sightings (47 in spring, 46 in winter and 16 in summer) of 10 species were detected during the 269.1 hours of effort. An additional 31 sightings (10 in spring, 17 in winter and 4 in summer) were detected during periods in which dedicated searching was not being conducted. Total sighting rates during dedicated searching (numbers per 100 n.miles searched) were similar for all the cruises (Table 1). Few animals were seen in the more inshore waters (Figs 2-4).

It was not possible to identify 37% of the sightings. Sperm whales (*Physeter macrocephalus*) were the dominant sighting during all cruises accounting for over 60% of the positively identified sightings. Table 2 summarises school size information by species or species group. The average estimated group size for sperm whales was substantially larger in winter.

DISCUSSION

Sightings effort and sightings rates

Despite the apparent high overlap of tracklines in Fig. 1, double counting is unlikely to have been a substantial problem as most of the criss-crossed tracklines represent searching effort on different cruises. Even when searching was in the same general area during a cruise (e.g. during setting and hauling), the actual tracklines were on different days and spatially distinct due to drift. As such, the data probably provide reasonably independent estimates of the sighting rates in those general areas.

Comparison of rates by activity

During the first two cruises, sightings rates during settings were 50-80% greater than during transits (during the subsequent cruises there was substantially less effort during

Table 1
Sighting data by season cruise. (T) = transit, (S) = setting, (H) = hauling, (To) = total within a cruise.

	Spring 1996				Winter 1997				Summer 1998				Winter 1999				Total			
	T	S	H	To	T	S	H	To	T	S	H	To	T	S	H	To	T	S	H	To
Distance searched (nm)	730.7	97.5	67.0	895.2	591.1	94.4	0	663.5	261.3	40.5	27.2	329.0	234.0	46.7	9.3	290.0	1795.0	279.1	103.5	2177.7
Time seacherd (hours)	74.3	13.9	23.9	112.1	60.2	16.8	0	77.0	31.1	6.7	9.7	47.4	23.6	6.4	2.6	32.7	189.1	43.7	36.2	269.1
Number of sightings	30	6	11	47	24	7	0	31	15	0	1	16	10	1	4	15	79	14	16	109
Number of sightings/100miles	4.1	6.2	16.4	5.3	4.2	7.4	-	4.7	5.7	0	3.7	4.9	4.3	2.1	43.1	5.2	4.4	5.0	15.5	5.0
Number of sightings/hour	0.40	0.43	0.46	0.42	0.40	0.42	-	0.40	0.48	0	0.10	0.34	0.42	0.16	1.52	0.46	0.42	0.32	0.44	0.41
Number of sperm whale pods	13	2	4	19	11	5	0	16	6	0	1	7	1	0	1	2	31	7	6	44
Number of pods per 100miles	1.8	2.1	6.0	2.1	1.9	5.3	-	2.4	2.3	0	3.7	2.1	0.4	0	10.8	0.7	1.7	2.5	5.8	2.0
Number of sperm whales	32	8	15	55	109	15	0	124	10	0	1	11	3	0	2	5	154	23	18	195
Number of pods per hour	0.17	0.14	0.17	0.17	0.18	0.30	-	0.21	0.19	0	0.10	0.15	0.04	0	0.38	0.06	0.16	0.16	0.17	0.16

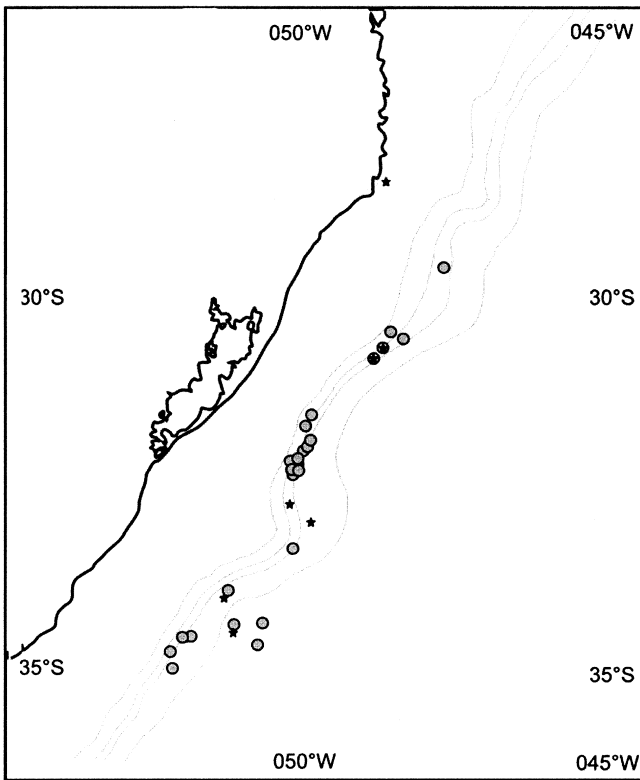


Fig. 2. The location of sperm whale (circle) and killer whale (star) sightings detected on dedicated effort during the Argo cruises. Each symbol represents one sighting, regardless of the number of animals. Isobars are in meters, from left to right: 200, 600, 1,000, 2,000.

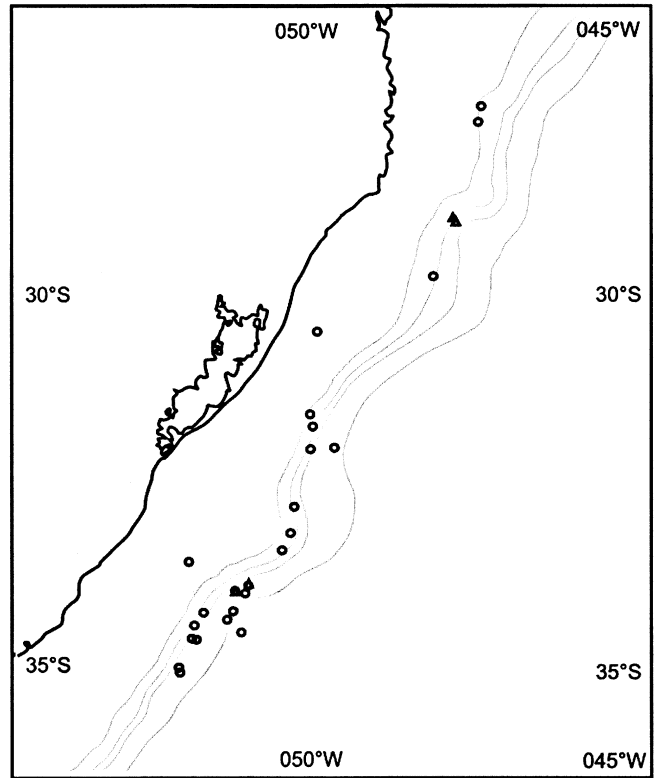


Fig. 4. The location of unidentified small dolphins (triangle) and other unidentified cetacean (circle) detected on dedicated effort during the Argo cruises. Each symbol represents one sighting, regardless of the number of animals. Isobars are in meters, from left to right: 200, 600, 1,000, 2,000.

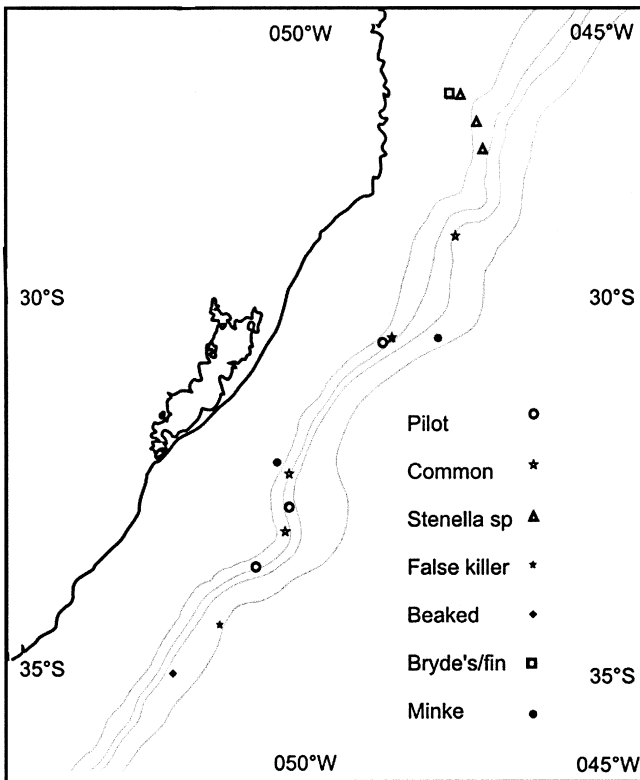


Fig. 3. The location of identified cetacean species or species groups detected on dedicated effort during the Argo cruises. Each symbol represents one sighting, regardless of the number of animals. Isobars are in meters, from left to right: 200, 600, 1,000, 2,000. Beaked = ziphiid; Bryde's/fin = either Bryde's or fin whale.

Table 2

Group sizes of species or species groups detected on dedicated searching effort. Only the group size by season is shown for sperm whales due to the small sample size for the others.

Species or species group	Season	Mean	Standard error	N
Sperm	Spring (96)	2.89	0.43	19
	Winter (97)	7.75	2.52	16
	(99)	2.50	0.50	2
	Summer (98)	1.57	0.43	7
	Total	4.43	1.00	44
Killer		3.00	0.82	9
Pilot		16.00	4.58	3
Minke		1.50	0.50	2
False killer		4.00	-	1
Spotted		4.67	1.45	3
Common		27.00	7.06	4
Beaked		1.00	-	1

setting operations and only one sighting was made). One likely factor in these higher rates is the lower speed of the vessel. There is a clear inverse relationship between the sighting rates per unit of distance and the speed of the vessel during the differing operational modes (Table 1). This is consistent with the fact that most of the sightings were of sperm whales which can have long periods between surfacing intervals (e.g. Lockyer, 1977). Clearly the probability of detecting a whale is dependent upon the probability of an animal surfacing within the time available for detection before the vessel passes. For sperm whales at least, the probability of detecting an animal on the track line (i.e. $g(0)$) will thus be substantially less than 1.0 (e.g. see

Kasamatsu and Joyce, 1995). As such, any sighting survey would need to estimate $g(0)$ if reliable absolute density or abundance estimates are to be obtained or if relative densities are to be compared between surveys where vessels move at varying speeds. The estimation of $g(0)$ is a complex and difficult problem in line transect surveys for cetaceans (e.g. see IWC, 1996b) and the variable speed experiments carried out thus far have not proved successful (Butterworth *et al.*, 1982; IWC, 1982; Butterworth, 1986; Zahl, 1989). However, the differential sighting rates observed here suggest that variable speed experiments could provide useful information on $g(0)$ for species with long periods between surfacings.

Another factor that may have resulted in higher sighting rates is the differential cross-shelf effort between transits and hauls (Fig. 1a, b). Except for the cross-shelf effort, there is no reason to suspect that longline setting locations were correlated with areas of high sperm whale abundance. They were chosen to sample the entire area and covered a wide range of depths. While the amount of searching effort was small, the sighting rates during the experimental searching during longline hauling was 350% greater than when transiting (Table 1). However, on a per unit of time basis, the sighting rates are remarkably similar for the different types of activities during spring and winter (Table 1). They were also similar for the summer cruise but with higher variability.

Table 1 also shows differences in the per nautical mile sighting rates. Whilst speed is still a factor, Table 3 shows that sea state conditions were not a factor. Most searching effort was undertaken at sea state 2 apart from during hauling, where there was approximately equal effort at sea states 2 and 3. Detection rates clearly declined at higher sea states and no confirmed sperm whale sightings occurred at sea states > 3 (58% of the unidentified sightings occurred at sea states > 2, 30% > 3 and 25% > 4). However, some of the unidentified sightings at higher sea states were probably

sperm whales as a large proportion of the unidentified sightings were in the area where positive sperm whale sightings were made.

Distribution and sightings

The sea surface temperature during the cruise ranged from 13.8-21.3°C in winter, from 20.3-26.3°C in spring and from 20.6-26°C in summer. The cetacean density was substantially higher in productive and temperate waters off southern Rio Grande do Sul, when compared with the more northerly sub-tropical waters of Santa Catarina.

Sperm whales

Sperm whales were detected both as single individuals and in schools of two or more (Table 2). Sperm whale schools accounted for 52% of all sperm whale sightings. They were concentrated in the southern continental slope area (i.e. to the south and north of Rio Grande, RS, Fig. 2) in the temperate and productive waters of this region (Table 4). Only one sighting (August 1999) was made north of 30°S (29°42'S) although approximately a third of the effort occurred there. There was no effort north of 30°S in the summer cruise so the results provide no information on their possible northern distribution during this season.

The high number and fidelity of the sperm whale sightings in the slope area off Rio Grande do Sul during the three seasons sampled suggest the year-round importance of the shelf border as a possible migration route and/or feeding ground for this species. In addition to two opportunistic sperm whale sightings aboard R/V *Atlântico Sul*, in autumn 1979 (approx. 40 animals, 33°46'S-50°40'W) and in spring 1980 (1 animal, 33°25'S-50°56'W), strandings data also show that sperm whales are not uncommon year round in the Rio Grande do Sul coast; there are at least 11 individual records from 1972-1999 (Pinedo *et al.*, 1992 MCP, unpublished data) and one mass stranding of 33 animals (Gomes, 1973). This area might be part of the 19th Century 'River La Plata' sperm whaling ground, reported (Clark, 1887 in Richards, 1993) as extending from 30-40°S and from 30-250 miles offshore, with takes of all size classes from September to May. The present demonstrate the continued importance of this area for sperm whales in the South Atlantic and clearly establish that the shelf edge break needs to be considered in any management plans for sperm whales in this region.

The apparent importance of the slope area for sperm whales has also been observed in the northwestern Atlantic, where they were also found to be the most common large whale (Hain *et al.*, 1985; Kenney and Winn, 1987; Gordon *et al.*, 1992). Kenney and Winn (1987) noted that in that area, the commercially harvested squid species of *Loligo pealei* and *Illex illecebrosus* are generally present along the entire shelf break. Species of *Loligo* and *Illex* (e.g. *L. plei*, *L. sanpaulensis* and *I. argentinus*) are also abundant in the shelf break area covered by the Argo cruises (Haimovici and

Table 3

Summary of sightings effort and sightings by sea state. The values in parentheses beneath the number of sightings is the sighting rate (numbers per 100 nm). Tran. = transit, Set. = setting, Haul. = hauling.

Sea state	Searched distance (nm)			Number of sightings (n)			Number of sperm whale sightings (n)		
	Tran.	Set.	Haul.	Tran.	Set.	Haul.	Tran.	Set.	Haul.
1	10.0	0	5.9	12	0	3	4	0	0
				(120.0)	(-)	(50.8)	(40.0)	(-)	(0.0)
2	699.4	123.2	39.0	42	11	6	26	7	3
				(6.0)	(8.9)	(15.4)	(3.7)	(5.7)	(7.7)
3	448.9	98.0	45.8	11	1	6	1	0	2
				(2.5)	(1.0)	(13.1)	(0.2)	(0.0)	(4.4)
4	312.1	44.0	10.2	12	2	1	0	0	1
				(3.8)	4.5	(9.8)	(0.0)	(0.0)	(9.8)
5	136.4	0	0	2	0	0	0	0	0
				(1.5)	(-)	(-)	(0.0)	(-)	(-)

Table 4

Latitudinal sightings distribution of sperm whales by season (n = number of sightings, h = dedicated effort, r = number of sightings per hour).

		30° - 31°			31° - 32°			32° - 33°			33° - 34°			34° - 35°		
		n	h	r	n	h	r	n	h	r	n	h	r	n	h	r
Spring	(96)	1	6	0.17	2	8	0.25	9	15	0.60	0	13	0	7	27	0.26
Winter	(97)	4	17	0.24	1	3	0.33	11	19	0.58	0	10	0	0	8	0
	(99)	0	3	0	0	3	0	0	0	-	1	10	0.10	0	5	0
Summer	(98)	0	0	-	0	8	0	0	6	0	1	16	0.06	6	18	0.33

Perez, 1991) and *I. argentinus* was the most abundant prey item found in the stomach of a male sperm whale stranded near Rio Grande (Clarke *et al.*, 1980). Sperm whales are well known to be primarily squid eaters and it is possible that these associations of sperm whales with the shelf break are related to the local abundance of squid species in this habitat.

Balaenopterids

Two minke whale (*Balaenoptera acutorostrata*) sightings (three animals, Fig. 3) and one humpback whale (*Megaptera novaeangliae*) sighting (two animals off effort at 27°S and 48°W) were made during the spring cruise. A photograph of one of the minke whales suggested that it belonged to the dwarf form described by Arnold *et al.* (1987). It was seen near the shelf break although the dwarf form is usually considered to be coastal. The form of the other two animals was unknown. Sightings in November-December in sub-tropical and temperate waters were unexpected for humpback whales and ordinary minke whales as the South Atlantic populations are generally considered to have migrated to Antarctic waters.

Killer whales (Orcinus orca)

Killer whales were the second most commonly sighted species ($n = 9$ on effort; $n = 6$ off effort) and were detected on all of the cruises (only one off effort on the spring cruise). All but one of the on effort sightings were near the shelf edge (Fig. 2); four were detected during longline hauling or setting operations. Four of six additional killer whale groups detected off effort were associated with longline operations. During such operations, the killer whales often remained around the vessel for long periods and came quite close to the vessel, and in some cases close to the longline itself, during the hauling process. Hooked fish were also observed to have been predated upon (with often only the head remaining). The sightings were clearly associated with both hauling and longline activity, suggesting that the animals have learned to be attracted to this type of human activity even before any fish are caught, possibly via sound or other stimulus.

Killer whales have been reported to predate on tuna and swordfish after they have been hooked on pelagic longlines (e.g. Northridge, 1984) and toothfish (*Dissostichus eleginoides*) caught in bottom longline fisheries (e.g. Ashford *et al.*, 1996). In southern Brazil, this interaction with pelagic longlines has been reported as a common problem with up to 50% of the tuna catch on a single commercial set being eaten (Secchi and Vaske, 1992). Swordfish fisheries are expanding in this area. As such, this interaction is likely to be an increasing problem which may require the development of appropriate management responses.

Nolan *et al.* (2000) reported aggressive behavioural interactions between killer whales and sperm whales during bottom longline operations for toothfish north of the Falkland Islands. The present cruise provided no evidence of such aggressive interspecific interactions although both were often associated with the same habitat (Fig. 2). In addition there was no indications of a positive association between the sperm whale sightings and longlining (sighting rates and initial sightings distances were similar, irrespective of vessel activity; sperm whales did not remain with the vessel during longline operations).

Other small cetacean sightings

Apart from killer whales, no delphinids were sighted in the summer cruise. During the spring cruises, there were few delphinid sightings (particularly large schools). Only five

schools of spotted dolphins, *Stenella* sp. (three on effort) were detected and the largest school was estimated to be at most ten individuals. During the winter cruises delphinid sightings were more frequent, represented by common dolphins, *Delphinus* sp. ($n = 10$, school size 4-40) pilot-whales, *Globicephala* sp. ($n = 4$, school size 4-25) (Fig. 3). From the sightings location, the common dolphins were probably be the short-beaked offshore form (*D. delphis*) and from earlier stranding records, the pilot-whales were probably of the long-finned form (*G. melas*) (Pinedo, 1994).

CONCLUSION

Dedicated research on cetaceans, particularly in offshore waters, is difficult and requires extensive ship time, which greatly limits opportunities for collecting data. Placing cetacean observers on vessels of opportunity is one approach that has been used (e.g. IWC, 1996c) to try and address this issue. The value of such data has been discussed within the Scientific Committee of the International Whaling Commission (IWC) which has recognised that observations from platforms of opportunity can provide useful information, particularly on distribution and behaviour (IWC, 1996a). The cetacean survey data collected during the Argo cruises demonstrates this. In particular, the data and experience gained from cruises such as these can establish the priority seasons/areas for management. This includes providing insights into potential species and/or fishery interactions requiring management attention, which may otherwise have remained unrecognised (without prior indication of a problem, dedicated research cruises to explore their possible existence can be hard to justify as a priority). They may also help to define requirements, protocols and designs for future abundance surveys for management purposes. Finally, the Argo cruises provided a vehicle for collecting variable speed data that would not normally be available in a dedicated sighting survey (obtaining some 200 hours of ship time for conducting such experiments would be difficult). The results indicate that such data could be of potential use in estimating $g(0)$ for long diving species such as the sperm whale.

It is also important to recognise the limitations of vessel of opportunity surveys. The greatest is the difficulty in obtaining adequate and representative coverage of the area. The Argo experience has shown that careful research activity coordination can substantially increase the amount of searching effort (see earlier). If the research activities span a broad enough area, the coverage may provide a sufficiently representative sample of the area. If appropriate effort and sightings data are collected, these should provide a basis for obtaining density estimates. Thus, during the Argo cruise, the basic data collected could support the calculation of line transect density estimates, and the overall cruise tracks covered by the vessel (when dedicated searching could potentially have been conducted) appeared to have been sufficient to provide broad and reasonably representative coverage of the entire survey area (not dissimilar to what might be anticipated from a dedicated sighting cruise). However, the sea and weather conditions in this particular outer slope and shelf region meant that the amount of time that searching could be completed was limited with long periods of unacceptable sightings conditions. This resulted in relatively uneven coverage across the area. The uneven coverage and small number of confirmed species sightings per cruise meant that it was not possible to obtain reliable quantitative density estimates. It should be noted that poor

weather conditions would have also affected a dedicated sighting survey with a similar amount of effort. This illustrates the difficulties that are likely to be encountered if a management procedure (such as the IWC's Revised Management Procedure; IWC, 1999) based on absolute abundance estimates from sighting surveys were to be applied in this area.

In conclusion, the results from these cruises demonstrate the importance of the shelf area habitat in southern Brazil for cetaceans, particularly sperm whales. The results also suggest that their heterogeneous distribution (e.g. concentration trends along the continental shelf) combined with the weather conditions means that obtaining reliable abundance and/or trend information from this habitat will be difficult. Such limitations need to be recognised when developing research and suitable management programmes for the area.

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