Key areas for beaked whales worldwide

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ABSTRACT

Beaked whales represent one of the groups of large mammals about which relatively little is still known. Many beaked whale species are known of from less than 50 records and one is known only from three partial skeletons. Beaked whales are subject to bycatch by fisheries, ingestion of plastics, accumulation of biocontaminants and adverse effects from anthropogenic noise. However, the inadequacy of knowledge about their biology means that developing effective conservation strategies can be difficult. We suggest that beaked whale conservation can best be achieved if, in consort with other approaches, key areas for beaked whales around the world can be identified. We suggest five criteria that can be used to identify key areas for beaked whales where, if human impacts were to occur, they would cause conservation concerns for beaked whales at a regional or global level. Using these criteria, 23 beaked whale key areas have been identified, based on existing knowledge contained in a database created from published and unpublished beaked whale records. In total, these 23 key areas covered the locations of almost 70% of all the beaked whale records in the database. However, for the identification of key areas to provide a useful tool for beaked whale conservation it is important not only that they are identified but that appropriate assessment and mitigation strategies are implemented within them to ensure that beaked whales are not adversely affected by human activities.

KEYWORDS: CONSERVATION; DISTRIBUTION; MONITORING; ATLANTIC OCEAN; BEAKED WHALES; HABITAT; GEOGRAPHY

INTRODUCTION

Less is known about many extant beaked whale species than about some mammals that became extinct thousands of years ago (e.g. mammoths) and most of what is currently known about the 21 species recognised by the International Whaling Commission (IWC) has been gleaned from beached animals, sometimes discovered far from the deep-water habitats in which they lived (Heyning, 1989; Mead, 1989a; MacLeod, 2000). Although beaked whales occur in all major seas and both hemispheres, some species are known from fewer than 50 published records worldwide (see MacLeod *et al.*, 2006). One species, the spade-toothed whale (*Mesoplodon traversii*), is known from only three partial skeletons (van Helden *et al.*, 2002) and several others have yet to be seen alive (Dalebout *et al.*, 2002). Directed studies of live animals are few (MacLeod, 2000) although that number has grown in recent years (e.g. Claridge and Balcomb, 1995; Whitehead *et al.*, 1997b; MacLeod and Claridge, 1999; Williams *et al.*, 1999; MacLeod and Zuur, 2005).

The lack of knowledge about beaked whales is primarily due to their oceanic distribution and their preferences for deep waters beyond the shelf edges where relatively few research vessels venture (MacLeod, 2000). However, there are also problems in identifying animals to species level at sea and even stranded animals can be mis-identified (Dalebout *et al.*, 1998; 2002; 2003; Barlow *et al.*, 2006). Beaked whales can be affected by human activities and known or suspected mortalities occur as a result of whaling, bycatch in fisheries for other marine species, ingestion of plastics, accumulation of biocontaminants and anthropogenic noise (e.g. Mitchell, 1977; Knap and Jickells, 1983; Simmonds and Lopez-Jurado, 1991; Law *et al.*, 1997; Frantzis, 1998; Poncelet *et al.*, 2000; Balcomb and Claridge, 2001; Waring *et al.*, 2002; Cox *et al.*, 2006).

The premise of this paper is that beaked whale conservation can best be achieved in the short-term if the traditional approaches for conserving large mammals (such as calculating and monitoring population sizes, investigating habitat requirements, monitoring habitat loss, fragmentability and connectivity, increasing community awareness, identifying potential threats and implementing appropriate mitigation measures) are focussed on identified areas of regional or global importance for beaked whales. Such 'key' areas are identified using relatively simple criteria and available knowledge. The list and the criteria can be revised in the future to take these advances in knowledge into account.

Despite this approach, it is important to stress that, particularly given current knowledge, it should not be taken to mean that beaked whales do not occur outside these areas. All beaked whales may be affected by anthropogenic activities and appropriate mitigation measures must be taken both within and outside key areas.

IDENTIFICATION OF KEY AREAS FOR BEAKED WHALES

Central to the identification of 'key' areas is a clear definition of what comprises a key area and how it is identified. In this paper, a key area is defined as any area where, if anthropogenic impacts were to occur, they might give rise to conservation concerns at a regional or global level. Four criteria are used to identify such key areas:

(A) areas where one or more beaked whale species have been regularly recorded at sea;
(B) areas used during movements between two or more key areas identified in criterion (A);
(C) areas with a high diversity of beaked whales where 'high' means records of more than 25% of all beaked whale species and at least 50% of all beaked whale genera;
(D) relatively small areas that cover a large portion, or all, of the known range of a species or isolated population.

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A fifth criterion (E), that can be used in additional support in the context of the above four, is for areas where beaked whales have already been affected by human impacts and where conservation concerns may exist or where they may be more vulnerable to future anthropogenic interference.

CONSTRUCTION OF A DATABASE TO IDENTIFY KEY AREAS FOR BEAKED WHALES

A global database containing 4,857 beaked whale records was constructed using all information available about sighting, bycatch, whaling, strandings and other types of records that, within the data, contained specific locations (Fig. 1). The data sources varied widely in content and included reviewed literature, published and unpublished reports, public and private datasets and on-going research. These records were collated into a single GIS database with a standardised format and were plotted using *ArcView 3.2* GIS software. Each record was examined for transcription errors (e.g. sightings on land), suspect information within specific records (e.g. where measurements or estimated size greatly exceeded published maximums for species or taxonomic group) and possible mis-identification (e.g. more refined identification than photographs could confirm). Problem records were isolated and original sources consulted for resolution. Resolution included assignment of lowest certain taxonomic level (e.g. *Mesoplodon* sp.) or removal from the database. After these quality control procedures, data were re-plotted and sorted using the criteria presented above to identify and define key areas for ziphiids. Finally, literature, unpublished reports and manuscripts that contained information (but not precise locations) about beaked whales' distribution were examined. These often described more general areas, for example around specific bathymetric features or in specific geographic areas.

While primary literature was the preferred resource, 'grey' literature often contained valuable and relevant information about distribution and occurrence. Accuracy of records found in grey literature was validated wherever possible. The entire process formed the basis for the key areas for beaked whales identified below. However, it should be noted that there was clearly a patchy distribution of data available for this study, which reflects inadequate sighting or survey effort in some places (e.g. throughout the west coast of Africa) and this limited the power of this study to identify all key areas for beaked whales that may exist.

PROPOSED KEY AREAS FOR BEAKED WHALES

Twenty-three areas were identified from the collated data and a review of published literature (Table 1; Fig. 2). In the summaries below, the limits were set based on the available data, details of which are provided afterwards. The number of records refers to the number for each key area which are currently held in the beaked whale database, rather than the total of all records in a key area. Where additional information has also been used, the appropriate references are provided.

1. The Atlantic Frontier

Limits: From the Scottish coasts between the southern Outer Hebrides, to Shetland, north to 62.30°N and the Faeroe Islands and as far west as 59.85°W (based on 120 records).

Three species of beaked whale from three genera have been recorded in this area (Table 2) and there are two specific areas which are important for beaked whales (Table 1). These are the region around the northern end of the Rockall Trough, particularly around the eastern end of the Wyville-Thompson Ridge and the Faeroe-Shetland Channel (Pollock *et al.*, 2000). Migration, at least for northern bottlenose whales (*Hyperoodon ampullatus*), is thought to occur through this area in late summer/early autumn and in late winter/early spring (MacLeod *et al.*, 2004b). However, this has not been confirmed by tracking the movements of individual animals.

The Atlantic Frontier therefore qualifies as a key area under criterion (A) and potentially (B).

2. The Bay of Biscay

Limits: From the European coast, out to a line between 48.53°N, 4.77°W-43.53°N, 5.84°W based on 131 records[1].

The Bay of Biscay has records for all six species of beaked whales (from three genera) that regularly occur in the North Atlantic, making it an area of high beaked whale

[1] With additional information from D. Walker (Organisation Cetacea), and A. Williams (Biscay Dolphin Research Programme).

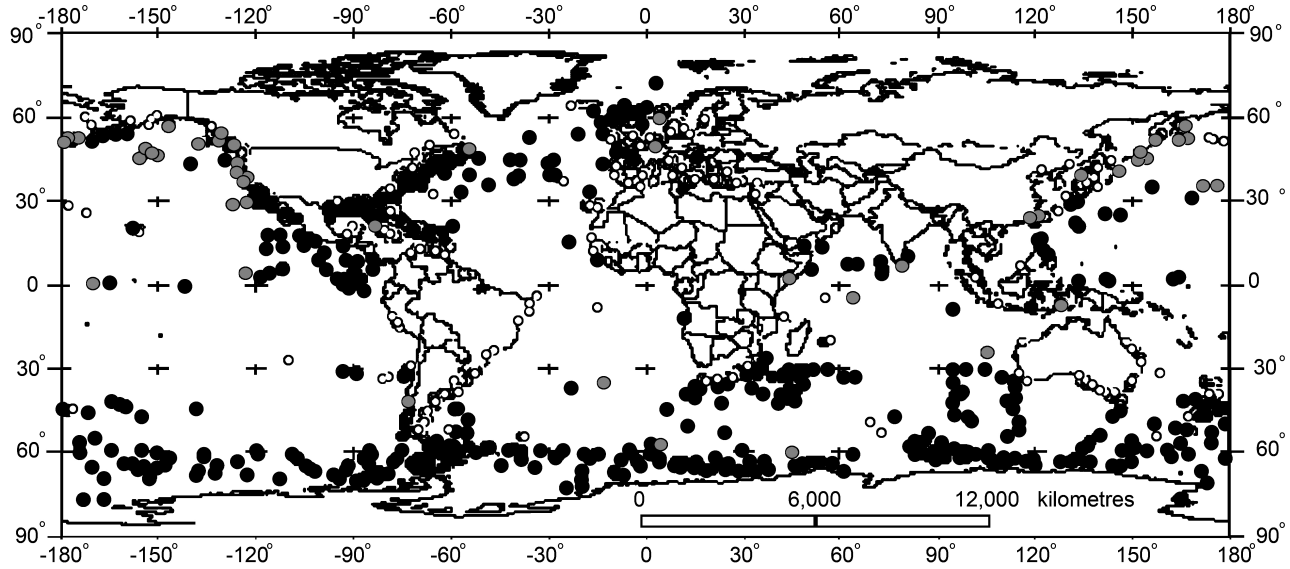

Fig. 1. Distribution of 4,857 records of beaked whale occurrence included in the global database of beaked whale records, which was used to identify beaked whale key areas. White —Strandings records; Black – Sightings records; Grey – Other records.

Table 1

Known key areas for beaked whales identified using the five criteria outlined in this study; (+) means criterion is probably met.

Known beaked whale key areas	Criteria					Specific areas known to be of importance in key area (criteria)	References
	A	B	C	D	E		
1. Atlantic Frontier	+	(+)				Northern end of the Rockall Trough (particularly around the eastern end of the Wyville-Thompson Ridge, approximately 59.4°N, 007.9°W (A), and the Faeroes-Shetland Channel, centred at approximately 61.7°N, 003.0°W (A, B).	Pollock *et al.* (2000); Weir (2000); MacLeod *et al.* (2004a).
2. Bay of Biscay	+		+			Southern Bay of Biscay around Cap Breton Canyon and along continental shelf edge (A).	Barriety (1962); Castells and Mayo (1992); Mead *et al.* (1988); Gannier *et al.* (2000); Poncelet *et al.* (2000); Williams *et al.* (1999); A. Williams (Biscay Dolphin Research Project) (pers. comm.); D. Walker (Organisation Cetacea) (pers. comm.).
3. Genoa Canyon	+						Azzellino *et al.* (2001).
4. Eastern Alboran Sea	+	(+)		(+)		Triangle between 36.34°N, 003.00°W, 36.51°N 002.52°W and 36.26°N, 002.79°W (A).	Sagarminaga and Cañadas (2003).
5. Western Greece	+				+	Ionian Sea (A) Kyperissiakos Gulf (E).	Politi *et al.* (1992); Politi *et al.* (1994); Pulcini and Angradi (1994); Frantzis (1998).
6. Azores	+		+			Around the island of Pico (A).	Richard (1936); Bruyns (1968); Clarke (1981); Reiner *et al.* (1993); Steiner *et al.* (1998); Leal *et al.* (2001).
7. Canaries	+		+		+	South of La Gomera (A), south-west of Tenerife 28.3°N, 16.9°W; 28.1°N, 16.8°W (A), Fuertaventura and Lanzarote (E).	Mead *et al.* (1988); Vonk and Martin (1988; 1989); Martin *et al.* (1990); Simmonds and Lopez-Jurado (1991); Montero and Martin (1992); Politi *et al.* (1992); Carrillo and Lopez-Jurado (1998); Carrillo and Martin (1999); Ritter and Brederlau (1999); Evans *et al.* (2001); Vidal Martin (pers. comm.).
8. The Gully, Nova Scotia	+			+		43.5-44.5°N, 058.5-060.0°W (A, D).	Whitehead *et al.* (1997a); Gowans *et al.* (2000); Dalebout *et al.* (2001); Hooker *et al.* (2002a); Hooker *et al.* (2002b).
9. North-eastern North America continental shelf margins	+		+		+		Ulmer (1941); Backus and Schevill (1961); Mitchell and Kozicki (1975); Leatherwood *et al.* (1976); CETAP (1982); Bane and Zullo (1980); Mead *et al.* (1988); Mead (1989a); Lien and Barry (1990); Waring *et al.* (1993); Nawojchik (1994); Tove (1995); Waring *et al.* (2001); Waring *et al.* (2002).
10. Northern Bahamas	+				+	Little Abaco Canyon, centred at approximately 26.6°N, 076.9°W (A), southern edge of Little Bahama Bank from 26.6°N 078.5°W to 25.9°N 077.3°W (E).	Claridge and Balcomb (1995); Balcomb and Claridge (2001); Evans *et al.* (2001); MacLeod *et al.* (2004b); MacLeod and Zuur (in press).
11. Northern Gulf of Mexico continental shelf margins	+					25.9-27.6°N and 96.0-90.8°W (A), an area bordered by the following co-ordinates: 26.6°N, 90.0°W; 27.0°N, 90.4°W; 27.7°N, 90.6°W; 28.0°N, 90.6°W; 29.2°N, 87.4°W 28.9°N, 87.1°W; 27.7°N, 88.0°W (A).	Jefferson and Shiro (1997); NOAA CD-ROM NODC-72.
12. Puerto Rico and the Virgin Islands	+						Varona (1964); Varona (1970); Erdman *et al.* (1973); Varona (1985); Mattila and Clapham (1989); Mignucci-Giannoni (1989); Mignucci-Giannoni (1996); Mignucci-Giannoni (1998); Rosario-Delestre *et al.* (1999); Roden and Mullin (2000); Swartz and Burks (2000); Swartz *et al.* (2001).
13. Californian shelf margins, USA	+		+	+		Waters 32.9-36.6°N (D).	Hubbs (1946); Houck (1958); Roest (1964); Mitchell (1968); Sullivan and Houck (1979); Dohl *et al.* (1981, 1983); Mead *et al.* (1988); Hill and Barlow (1992); Lynn and Reiss (1992); Carretta and Forney (1993); Forney (1994); Barlow and Gerrodette (1996); Carretta *et al.* (2000, 2002); Dalebout *et al.* (2002).
14. Hawaii	+						Shallenberger (1981); Mobley *et al.* (2000); Baird (pers. comm.).
15. Eastern Tropical Pacific	+		+	+		From the central and northern South American coast west to approximately 135.0°W (A, C). From the South American coast westward around 30°S (A).	Vidal *et al.* (1993); Dawson *et al.* (1998); Perrin *et al.* (1999); Pitman and Lynn (2001); H. Whitehead (Dalhousie University) (pers. comm.).
16. Galapagos	+					1.6°N-1.3°S, 92.6-89.9°W.	Robinson *et al.* (1983); Palacios (1996); Perrin *et al.* (1999); Daniel Palacios, unpublished data); H. Whitehead (Dalhousie University) (pers. comm.)
17. Falkland Is./Tierra del Fuego	+		+				Goodall (1978); White *et al.* (2002).

Cont.

Table 1 cont.

Known beaked whale key areas	Criteria					Specific areas known to be of importance in key area (criteria)	References
	A	B	C	D	E		
18. Indian Ocean around South Africa	+		+	(+)			Talbot (1960); Ross (1969); Gambell *et al.* (1975); Nemoto *et al.* (1980); Ross (1984); Findlay *et al.* (1992).
19. Japan	+	+	+			34.0-36.0° N, 139.0-143.0°E (designated Area I); 37.0-38.0°N, 141.0-144.0°E (designated Area II); off the coast of Hokkaido, particularly around 44.0°N, 145.0°E. Areas I (particularly in an area centred at approximately 34.5°N, 139.5°E) II and VII.	Omura *et al*. (1955); Nishiwaki and Oguro (1971); Nishiwaki and Oguro (1972); Nishiwaki and Kamiya (1958); Nishiwaki *et al.* (1972); Miyashita (1986); Miyazaki *et al.* (1987); Kasuya and Miyashita (1997); Marine Mammal Stranding Database (National Museum of Science, Tokyo, Japan).
20. Southwestern Australia	+						Gales *et al.* (2002); IWC (unpublished data).
21. Tasmania and southeastern Australia			+	+			Hale (1931); Guiler (1966); Guiler (1967); Aitken (1971); McCann (1975); Gianuca and Castello (1976); Dixon (1980); Lewis (1988); Mead (1989a); Dixon and Frigo (1995).
22. New Zealand	+		+	(+)		To the east and south of South Island (A).	Oliver (1937); Gaskin (1971); McCann (1975); Gianuca and Castello (1976); Fordyce *et al.* (1979); Mead and Baker (1987); Mead (1989a, b); Baker and van Helden (1999); Baker (2001); van Helden *et al.* (2002); IWC (unpublished data).
23. Southern Ocean and Antarctic waters	+					Antarctic Peninsula from 65.2°S, 066.2°W-70.3°N, 094.6°W (A).	Gianuca and Castello (1976); Miyazaki and Kato (1988); Kasamatsu *et al.* (1993); Bowles *et al.* (1994); Ponganis *et al.* (1995); Hobson and Martin (1996); Pankow *et al.* (1997); Pierpoint *et al.* (1997); Leaper and Scheidat (1998); Branch and Butterworth (2001).

diversity (Table 2). The Bay of Biscay also has had repeated sightings of beaked whales at sea, including Cuvier's beaked whales (*Ziphius cavirostris*), northern bottlenose whales and various *Mesoplodon* species (e.g. Castells and Mayo, 1992; Williams *et al.*, 1999; D. Walker, pers. comm.). Sightings of Cuvier's beaked whales are particularly common around the Cap Breton Canyon, where Williams and colleagues have been studying them and have seen some individuals on a number of occasions (A. Williams, pers. comm.). Preliminary research also suggests that *Mesoplodon* species are distributed throughout the deep waters areas of this key area (A. Williams, pers. comm.).

The Bay of Biscay therefore qualifies as a key area under criteria (A) and (C).

3. The Genoa Canyon

Limits: From 43.51°N, 9.68°E, due west to the French coast and due north to the Italian coast (based on 75 records).

The Genoa Canyon lies in the north west of the Ligurian Sea, an area of the Mediterranean between Italy, France and northern Sardinia. Although Cuvier's beaked whale is the only species that has been recorded in this area, it is one of the few areas in the Mediterranean where they are regularly sighted (e.g. D'Amico *et al.*, 2001; Azzellino *et al.*, 2004).

The Genoa Canyon therefore qualifies as a key area under criterion (A).

4. Eastern Alboran Sea

Limits: A pentagon with corners at 36.52°N, 3.10°W; 35.98°N, 3.10°W; 36.08°N, 2.87°W; 36.52°N, 2.13°W and 36.47°N, 2.80°W (based on 27 records and Sagarminaga and Cañadas, 2003[2]).

Sagarminaga and Cañadas (2003) have recorded many sightings of Cuvier's beaked whales in the eastern Alboran Sea, as well as occasional sightings of northern bottlenose whales. The area represents an area of regular sightings of beaked whales and is the only known area outside the North Atlantic Ocean where northern bottlenose whales have been observed. In addition, its position between the North Atlantic and the main body of the Mediterranean means that it is potentially important for exchange of genetic information between these two areas, although it is not currently known whether such mixing occurs.

The eastern Alboran Sea therefore qualifies as a key area under criterion (A) and possibly (B) and (D).

5. Western Greece

Limits: Waters west of Greece and southern Albania from 39.92-36.41°N (based on 29 records and additional information from Frantzis, 1998).

Cuvier's beaked whale is the only beaked whale species regularly recorded in the eastern Mediterranean and it is regularly sighted in the deep waters around western Greece (e.g. Politi *et al.*, 1992; 1994; Pulcini and Angradi, 1994). In addition, an 'atypical' mass stranding of 13 Cuvier's beaked whales occurred in this region in 1996. This stranding has been linked to the use of naval sonars in the local area (Frantzis, 1998; Cox *et al.*, 2006).

Western Greece therefore qualifies as a key area under criterion (A) augmented by (E).

6. The Azores

Limits: 35.50-43.75°N, 23.50-32.25°W (based on 10 records and additional information from Clarke, 1981; Reiner *et al.*, 1993; Steiner *et al.*, 1998 and Leal *et al.*, 2004).

The Azores are situated on the border between the colder waters of the northern North Atlantic and the warmer waters of the Gulf Stream. These productive waters have a relatively high abundance and diversity of cetaceans in general and beaked whales in particular. Six beaked whale species from three genera have been recorded in the Azores (Table 2). The Azores also has a very high number of beaked

[2] With additional information from A. Cañadas (SMRU).

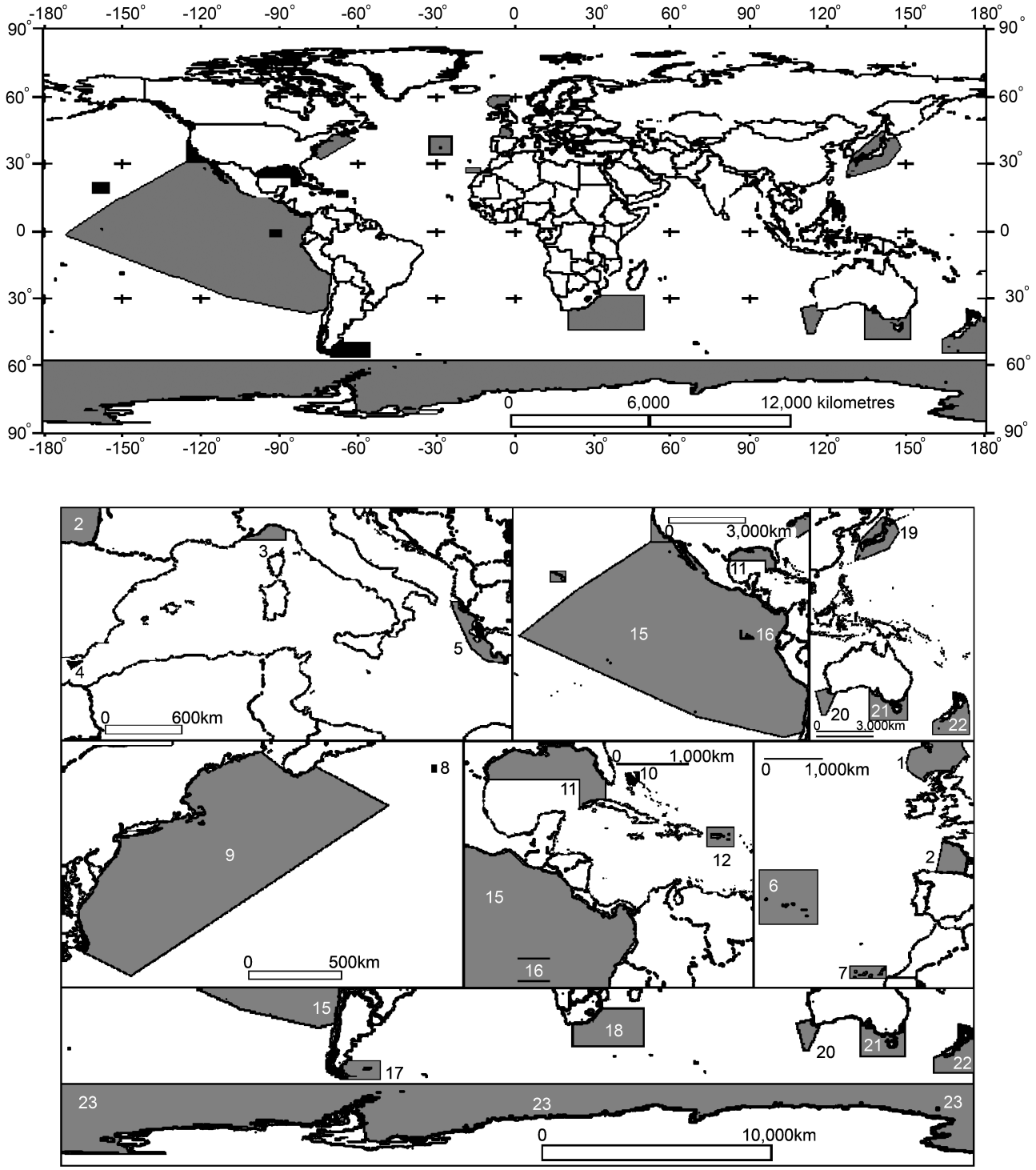

Fig. 2. A. (top) Global distribution of the 23 areas of the world which fulfil one or more of the criteria used to define a beaked whale key area based on the currently available information. B. (bottom) Detailed views of each key area by oceanic region. (1) The Atlantic Frontier; (2) The Bay of Biscay; (3) The Gulf of Genoa; (4) The eastern Alboran Sea; (5) Western Greece; (6) The Azores; (7) The Canaries; (8) The Gully, Nova Scotia; (9) North-eastern North American continental shelf margins; (10) Northern Bahamas; (11) Northern Gulf of Mexico continental shelf margins; (12) Puerto Rico and the Virgin Islands; (13) The Californian shelf margins; (14) Hawaii; (15) The eastern tropical Pacific; (16) The Galapagos; (17) Tierra del Fuego and the Falkland Islands; (18) The Indian Ocean around South Africa; (19) Japan; (20) South-western Australia; (21) Tasmania and south-eastern Australia; (22) New Zealand; (23) Southern Ocean and Antarctica.

whale sightings relative to other parts of the world, for example Leal *et al.* (2004) reported 147 sightings of beaked whales made between June-October 2000. Of particular interest are regular sightings of northern bottlenose whales and Sowerby's beaked whales (*M. bidens*), which may represent the southernmost populations of these species in the eastern Atlantic.

The Azores therefore qualify as a key area under criteria (A) and (C).

7. The Canaries

Limits: 27.50-29.50°N, 13.25-18.75°W (based on 60 records).

Five beaked whale species from three genera have been recorded in the Canaries (Table 2). Blainville's beaked whales (*M. densirostris*) and Cuvier's beaked whales have been repeatedly sighted (e.g. Carrillo and Lopez-Jurado, 1998; Ritter and Brederlau, 1999; F. Ritter, pers. comm.) and there have been at least five atypical mass strandings

involving four beaked whale species in the Canaries; several of these have been linked to military activities in the local area (e.g. Simmonds and Lopez-Jurado, 1991; Brownell *et al.*, 2006; Cox *et al.*, 2006; V. Martin, pers. comm.).

The Canaries therefore qualify as a key area under criteria (A) and (C) augmented by (E).

8. The Gully, Nova Scotia

Limits: 43.7-44.0°N, 58.8-59.0°W (based on 950 records).

The Gully, a submarine canyon off Nova Scotia, is home to a resident population of approximately 133 northern bottlenose whales (95% CI: 111-166, Gowans *et al.*, 2000). The Gully population is the most intensively studied population of beaked whales in the world and is thought to be relatively isolated and genetically separate from its nearest neighbouring populations of this species (Dalebout *et al.*, 2001). The Gully covers a relatively small area, around 200km^2 that is the core area for this population and where it would be extremely vulnerable to anthropogenic impacts. Individuals may remain resident in the Gully for an average of 20 days at a time and continually enter and leave it (Hooker *et al.*, 2002b). The population may have previously been depleted by whaling activity and thus may be vulnerable to further disturbances (Gowans *et al.*, 2000). This population is classified as 'endangered' by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC 2002[3]) and the Gully is classified as a 'Pilot Marine Protected Area' (Hooker *et al.*, 2002a).

The Gully therefore qualifies as a key area under criteria (A) and (D).

9. Northeastern North America Continental Shelf Margins

Limits: From Cape Hatteras to southern Nova Scotia and east to the start of the Abyssal plain (based on 498 records and additional information from Waring *et al.* (2001).

This key area covers an area between the edge of the continental shelf and the start of the abyssal plains from Cape Hatteras, North Carolina to the vicinity to Nova Scotia, Canada and has a high diversity of beaked whale species (six species from three genera, Table 2). Sightings data suggests that beaked whales have a widespread distribution along the shelf edge and over the continental slope and rise, with some emphasis on Cape Hatteras and Georges Bank offshore areas (CeTAP, 1982; Waring *et al.*, 1993; Waring *et al.*, 2001). For *Mesoplodon* species and Cuvier's beaked whale, the minimum population of these two combined is estimated to be 2,419 (CV=0.34, Waring *et al.*, 2002). Past human impacts on beaked whales in this area include bycatch in pelagic driftnet fisheries and Waring *et al.* (2002) estimated annual fisheries-related mortalities at 4-60 individuals during 1989-1998.

This region therefore qualifies as a key area under criteria (A) and (C) augmented by (E).

10. Northern Bahamas

Limits: Northwest and northeast Providence Channels from a line between Freeport and northern Andros east to northern Eleuthra and southern Abaco and along the eastern side of Little Bahama Bank to 26.75°N, 76.80°W (based on 47 records).

There are two areas which are known to be of particular importance for beaked whales: (1) around Little Abaco Canyon (centred at approximately 26.6°N, 76.9°W), where Blainville's beaked whales are regularly seen, including repeated sightings of the same individuals within and between years (Claridge and Balcomb, 1995; MacLeod *et al.*, 2004a; MacLeod and Zuur, 2005); and (2) south and west of the southern tip of Great Abaco. Blainville's and Cuvier's beaked whales have been recorded in this latter area (Claridge and Balcomb, 1995) and both species were involved in a mass stranding incident there in March 2000; military sonar in the Northeast and Northwest Providence Channels has been implicated (Claridge and Balcomb, 1995; Balcomb and Claridge, 2001; Cox *et al.*, 2006).

The northern Bahamas therefore qualifies as a key region under criterion (A) augmented by (E).

11. Northern Gulf of Mexico Continental Shelf Margins

Limits: North of a line from the US/Mexican border, east to 84.87°W, south to the western end of Cuba, east to 81.34°W and North to Florida (based on 170 records).

Four different species of beaked whales (Table 2) and a relatively high number of sightings have been recorded in the Gulf of Mexico area (NOAA). Most of these sightings occurred in two adjacent areas (Table 1).

This region therefore qualifies as a key region under criterion (A).

12. Puerto Rico and the Virgin Islands

Limits: 16.75-19.50°N, 64.0-67.75°W (based on 69 records and Erdman *et al.*, 1973; Mattila and Clapham, 1989; Mignucci-Giannoni, 1998 and Swartz *et al.*, 2002).

Three species of beaked whales have been recorded around Puerto Rico and the Virgin Islands (Table 2). Cuvier's beaked whales have been regularly sighted in the deep waters surrounding the Puerto Rico Bank, with most to the south of the Bank especially around the deep waters leading into and including the Anegada Passage (Erdman *et al.*, 1973; Mattila and Clapham, 1989; Mignucci-Giannoni, 1998; Swartz *et al.*, 2002). *Mesoplodon* species have been sighted to the south of the Puerto Rico Bank, to the north of St. Croix including the Anegada and Mona Passages and to the east towards the Dominican Republic and Cuba (Varona, 1964; 1970; 1985; Mattila and Clapham, 1989; Roden and Mullin, 2000; Swartz *et al.*, 2002).

This region therefore qualifies as a key area under criterion (A).

13. Californian Shelf Margins

Limits: From the Californian coast, west to 125.0°W (based on 70 records and Dohl *et al.*, 1983; Hill and Barlow, 1992; Carretta and Forney, 1993; Forney, 1994; Barlow and Gerrodette, 1996; Carretta *et al.*, 2000; 2002).

Perrin's beaked whale (*M. perrini*), one of the least known species of beaked whale is currently only known from Californian waters. It was first described in 2002 and is only known of from a total of five stranded animals and one possible sighting at sea ranging from 32.9°-36.6°N (Dalebout *et al.*, 2002). The known range is thus restricted to a small area off the Californian coast. Six other species of beaked whales have been recorded in Californian waters (Table 2). Several of these species, including Baird's beaked whales, Blainville's beaked whales, *Mesoplodon* species and Cuvier's beaked whales have been observed repeatedly in Californian waters, particularly in the southern California Bight. The latter species is probably the most numerous, with an estimated population of over 4,000 (Carretta *et al.*, 2000; 2002).

[3] *www.cosewic.gc.ca/eng/sct1/searchform_e.cfm.*

Table 2

Diversity of beaked whale species in each beaked whale key area. Key areas highlighted in bold are those classified as high diversity in terms of number of species (more than 25% of known species) and genera (at least 50% of all known genera).

Known beaked whale key areas (in order of diversity)	**Total number of beaked whale species**	**Total number of beaked whale genera**	Arnoux's beaked whale	Baird's beaked whale	Northern bottlenose whale	Southern bottlenose whale	Longman's beaked whale	Andrews' beaked whale	Sowerby's beaked whale	Hubbs' beaked whale	Blainville's beaked whale	Gervais' beaked whale	Ginkgo-toothed beaked whale	Gray's beaked whale	Hector's beaked whale	Layard's beaked whale	True's beaked whale	Perrin's beaked whale	Pygmy beaked whale	Spade-toothed beaked whale	Stejneger's beaked whale	Shepherd's beaked whale	Cuvier's beaked whale	References
22. New Zealand	**11**	**5**	+		+		+			+			+	+	+				+	+		+	+	Oliver (1937); Gianuca and Castello (1976); McCann (1975); Fordyce *et al*. (1979); Mead and Baker (1987); Mead (1989a, b); Baker and van Helden (1999); Baker (2001); van Helden *et al*. (2002).
21. Tasmania and South-eastern Australia	**10**	**4**	+		+		+			+		+	+	+	+	+	+						+	Hale, (1931); Guiler (1966); Guiler (1967); Aitken (1971); McCann (1975); Dixon (1980); Dixon and Frigo (1995); Mead (1989a); Baker (2001).
15. Eastern Tropical Pacific	**9**	**5**		+		+	+			+		+							+	+		+	+	Brownell *et al*. (1976); Mitchell (1968); Clarke *et al*. (1978); Vidal *et al*. (1993); Palacois (1996); Aguayo *et al*. (1998); Pitman *et al*. (1999); Pitman and Lynn, (2001); van Helden *et al*. (2002).
18. Indian Ocean around South Africa	**9**	**5**	+			+	+			+			+	+	+	+	+						+	McCann and Talbot (1963); Ross (1969); Gambell *et al*. (1975); Ross (1984); Dalebout *et al*. (2003).
17. Falkland Islands and Tierra del Fuego	**8**	**5**	+			+								+	+	+					+	+	+	Gianuca and Castello (1976); Goodall (1978); Mead and Baker (1987); Baker (2001).
13. Californian Shelf Margins	**7**	**3**		+						+	+		+					+					+	Hubbs (1946); Houck (1958); Roest (1964); Mitchell (1968); Mead *et al*. (1988); Lynn and Reiss (1992); Dalebout *et al*. (2002).
19. Japan	**7**	**4**		+			+			+	+		+								+		+	Omura *et al*. (1955); Nishiwaki and Kamiya (1958); Nishiwaki and Oguro (1972); Nishiwaki *et al*. (1972); Miyazaki *et al*. (1987); Marine Mammal Stranding Database (National Museum of Science, Tokyo, Japan).
2. Bay of Biscay	**6**	**3**			+				+		+	+					+						+	Barriety, (1962); Mead *et al*. (1988); Gannier *et al*. (2000); Poncelet *et al*. (2000); Williams (pers. comm.).
6. Azores	**6**	**3**			+				+		+	+					+						+	Reiner *et al*. (1993); Steiner *et al*. (1998).
9. North-eastern North American Shelf Margins	**6**	**3**			+				+		+	+					+						+	Ulmer, (1941); Mitchell and Kozicki (1975); Bane and Zullo (1980); Mead (1989a); Lien and Barry (1990); Nawojchik (1994).
20. South-western Australia	5	2																						Dixon (1980); Baker (2001); Gales *et al*. (2002); IWC (unpublished data).
23. Southern Oceans and Antarctic Waters	5	4	+			+								+		+							+	Gianuca and Castello (1976); Miyazaki and Kato (1988); Hobson and Martin (1996); IWC (unpublished data).
7. Canaries	5	3			+						+	+					+						+	Vonk and Martel (1988, (1989); Martin *et al*. (1990); Montero and Martin (1992); Ritter and Breberlau (1999).
11. Northern Gulf of Mexico Shelf Margins	4	2							+		+	+											+	Jefferson and Shiro (1997).
16. Galapagos	4	3					+						+						+				+	Robinson *et al*. (1983); Palacois (1996); Pitman *et al*. (1999); Palacios (unpublished data).
1. Atlantic Frontier	3	3			+				+														+	Pollock *et al*. (2000); MacLeod *et al*. (2006).
12. Puerto Rico	3	2									+	+											+	Mignucci-Giannoni (1989); Mignucci-Giannoni (1996); Rosario-Delestre *et al*. (1999).
14. Hawaii	3	3					+				+												+	Mitchell, (1968); Shallenberger, (1981); Pitman *et al*. (1999).
10. Northern Bahamas	2	2									+												+	Claridge and Balcomb (1995); MacLeod *et al*. (2004b).
4. Eastern Alboran Sea	2	2			+																		+	Sagarminaga and Cañadas (2003).
8. The Gully, Nova Scotia	2	2			+				+															Whitehead *et al*. (1997a, b); Hooker and Baird (1999b).
3. Genoa Canyon	1	1																					+	Azzellino *et al*. (2001).
5. Western Greece	1	1																					+	Frantzis (1998).

The California shelf margins therefore qualify as a key area under criteria (A), (C) and (D).

14. Hawaii

Limits: 18.5-22.5°N, 154.5-160.25°W (based on three records and additional information from Shallenberger, 1981; Mobley *et al.*, 2000; Anon., 2003; Baird *et al.*, 2003; R. Baird, pers. comm.).

Three species of beaked whale have been recorded in Hawaiian waters (Table 2). Anon. (2003) reported sightings of 30 groups of beaked whales, while Baird *et al.* (2003) reported six sightings from a survey in May/June 2003. The information from these surveys suggest regular occurrences of beaked whales in this area. The main species involved in these sightings, and other published accounts, are Blainville's beaked whales and Cuvier's beaked whales around the Hawaiian archipelago (Shallenberger, 1981; Mobley *et al.*, 2000; Anon., 2003; Baird *et al.*, 2003; R. Baird, pers. comm.).

Hawaii therefore qualifies as a key area under criterion (A).

15. Eastern Tropical Pacific (ETP)

Limits: From the coasts of the Americas between the US/Mexican border and 35.0°S, west to a maximum of 170.0°W and including the Gulf of California (based on 105 records and data from Pitman and Lynn, 2001).

Within this area, sightings of beaked whales are relatively common and six species have been recorded in the ETP (Table 2). The vast majority of sightings (and indeed strandings) of the pygmy beaked whale (*M. peruvianus*) have been in the ETP and as a result, Pitman and Lynn (2001) consider this species to be endemic to this area. Sighting of other species include Blainville's beaked whale, Longman's beaked whale (*M. pacificus*) and Cuvier's beaked whale (Vidal *et al.*, 1993; Dawson *et al.*, 1998; Pitman *et al.*, 1999; Pitman and Lynn, 2001; H. Whitehead, pers. comm.).

The ETP therefore qualifies as a key area under criteria (A), (C) and (D).

16. Galapagos

Limits: 1.25°S-1.50°N, 89.0-93.25°W (based on 48 records).

The Galapagos Islands represent a sub-division of the ETP key area and are considered separately due to the different oceanographic conditions provided in comparison with the surrounding oceanic waters. Four species of beaked whales are known to occur around the Galapagos Islands (Table 2). Beaked whales have regularly been sighted around the Galapagos Islands, e.g. Palacios (1999; unpublished data) recorded sightings of 34 groups of beaked whale, including six sightings of Cuvier's beaked whales totalling 21 animals and three groups of *Mesoplodon* species (including one group of pygmy beaked whales) totalling 13 animals. These sightings have all been recorded 1.6°N-1.3°S, 92.6-89.9°W.

The Galapagos therefore qualifies as a key area under criterion (A).

17. The Falkland Islands and Tierra del Fuego

Limits: From Tierra del Fuego and the South American coast, from 48.5-59.5°S east to 54.50°W (based on 61 records).

Eight species of beaked whale of five genera have been recorded in this area, giving it a high diversity of species (Table 2). Southern bottlenose whales (*H. planifrons*) and a lesser number of *Mesoplodon* species, have been regularly sighted around the Falkland Islands (White *et al.*, 2002).

This region therefore qualifies as a key area under criteria (A) and (C).

18. Indian Ocean around South Africa

Limits: 28.25-41.25°S, 21.25-49.25°E (based on 127 records).

The Indian Ocean east of South Africa has a relatively high diversity of beaked whale species, with nine species from five genera having been recorded in this area (Table 2). Of particular interest are records of True's beaked whale (*M. mirus*). This species is only known to exist in three areas in the Southern Hemisphere; Australia, South Africa and South America (McCann and Talbot, 1963; Ross, 1969; Dixon and Frigo, 1994; Bannister *et al.*, 1996; de Souza *et al.*, 2004). Whether these represent three separate populations, or parts of the same population is unknown. Until this is clarified, it may be wise to consider each as a separate population. Under such an assumption, South Africa may represent a large portion of the area inhabited by one population. The waters around South Africa, particularly in the Indian Ocean to the east, have had relatively high numbers of sightings and have whaling records of southern bottlenose whales, with additional sightings of Cuvier's beaked whales and *Mesoplodon* species (Gambell *et al.*, 1974; Nemoto *et al.*, 1980; Ross, 1984; Findlay *et al.*, 1992).

This region therefore qualifies as a key area under criteria (A) and (C) and possibly (D).

19. Japan

Limits: All waters surrounding Japan out to the abyssal plain, including the East China Sea (based on 188 records and Omura *et al.*, 1955; Nishiwaki and Oguro, 1972; Miyashita, 1986 and Kasuya and Miyashita, 1997).

Japan has a high diversity of beaked whales, with seven species of five genera recorded in the area (Table 2). The majority of known records (15 out of 23) of the ginkgo-toothed beaked whale (*M. ginkgodens*), come from Japanese waters (Nishiwaki and Kamiya, 1958; Nishiwaki *et al.*, 1972; Miyazaki *et al.*, 1987; Marine Mammal Stranding Database, Tokyo, Japan). The Japanese have hunted Baird's beaked whales (*Berardius bairdii*) in deep waters off their coasts for many years (e.g. Omura *et al.*, 1955; Nishiwaki and Oguro, 1971; Kasuya *et al.*, 1997). Cuvier's beaked whales were also taken opportunistically but are no longer hunted (Nishiwaki and Oguro, 1972; Anon., 2004). Coastal whaling is active in Chiba, Miyagi and Hokkaido and the annual quota for Baird's beaked whale was 62 animals in 2004 (Anon., 2004). Miyashita (1986) estimated the 1984 summer population of Baird's beaked whales off the Pacific coast of Japan at a minimum of 4,220 animals. Kasuya and Miyashita (1997) reviewed the distribution of Baird's beaked whales off Japan using sightings data obtained during cruises from 1982-1984, resulting in 320 school being studied. They reaffirmed the hypothesis of three stocks, i.e. Sea of Japan, Pacific Coast and Okhotsk Sea, with some seasonal migration of the last stock off eastern Hokkaido.

Japan therefore qualifies as a key area under criteria (A), (B) and (C) augmented by (E).

20. Southwestern Australia

Limits: Along the southwestern Australian coast from 32.08°S, 115.74°E-34.54°S, 118.90°E to as far as 44.75°S and 109.25°E (based on 19 records).

Five species of beaked whale have been recorded in southwestern Australia (Table 2). These include the poorly known Hector's (*M. hectori*) and Andrews' (*M. bowdoini*) beaked whales. In addition, there have been regular sightings of beaked whales at sea, particularly to the south of the Australian coast. These include sightings of *Mesoplodon* species and Cuvier's beaked whales (Gales *et al.*, 2002; IWC, unpublished data).

Southwestern Australia therefore qualifies as a key area under criterion (A).

21. Tasmania and Southeastern Australia

Limits: Along the Australian coast from 134.0-151.5°E, 47.0°S (based on 48 records).

Tasmania and southeastern Australia has the second highest diversity of beaked whale species for any of the key areas identified here, with records of ten species (Table 2). As noted above it is also one of the three areas of the Southern Hemisphere where True's beaked whale has been recorded. Following the approach for key area 18, it may be wise to consider the animals in this area as a separate population.

The region therefore qualifies as a key area under criterion (C) and possibly (D).

22. New Zealand

Limits: Waters surrounding New Zealand, south to 53.5°S and east to 180°E (based on 119 records).

New Zealand has the highest diversity of beaked whales of any of the key areas identified here, with records of eleven species from five genera (Table 2). These waters may be globally important for four poorly known species, of which no live sightings have been confirmed. The majority of known records for Andrews' beaked whales (21 out of 35) come from New Zealand, or the nearby Chatham Islands, Campbell Islands and Macquarie Island (Baker, 2001). Similarly for Hector's beaked whales, 11 out of the 25 published records come from this area (Mead, 1989a; Baker *et al.*, 2001). For the spade-toothed whale, only three records are known around the world and one of these records comes from New Zealand and a second from the neighbouring Chatham Islands (van Helden *et al.*, 2002). Finally, for Shepherd's beaked whale (*Tasmacetus shepherdi*) five of the nine published records come from New Zealand (Mead, 1989b). There have been numerous beaked whale sightings in waters around New Zealand, mainly *Mesoplodon* species and Cuvier's beaked whales. The majority of these have been to the east and south of South Island (Gaskin, 1971; IWC, unpublished data).

New Zealand therefore qualifies as a key area under criteria (A), (C) and probably (D).

23. Southern Ocean and Antarctic Waters

Limits: South of 57.5°S to the ice edge and beyond (based on 347 records).

Arnoux's beaked whale (*B. arnuxii*) and the southern bottlenose whale are commonly recorded in the Southern Ocean, particularly around the Antarctic convergence (60.0-70.0°S) and as far south as the ice edge, and indeed in polynas within the ice itself (Cherry-Garrard, 1922; Gianuca and Castello, 1976; Miyazaki and Kato, 1988; Hobson and Martin, 1996). In addition, *Mesoplodon* species, such as Gray's beaked whale (*M. grayi*), the strap-toothed beaked whale, and Cuvier's beaked whale have also been recorded in these waters (e.g. Gianuca and Castello, 1976; Miyazaki and Kato, 1988; Kasamatsu *et al.*, 1993; Bowles *et al.*, 1994; Ponganis *et al.*, 1995; Hobson and Martin, 1996; Pankow *et al.*, 1997; Pierpoint *et al.*, 1997; Leaper and Scheidat, 1998; Branch and Butterworth, 2001). Branch and Butterworth (2001) estimated a population of about 72,000 southern bottlenose whales in the Antarctic south of 60.0°S. The surveys from which this estimate was obtained were designed to obtain Antarctic minke whale (*Balaenoptera bonaerensis*) population estimates and as a result, did cover the entire range of the beaked whale species in the Southern Ocean, but did not correct for animals missed on the trackline.

DISCUSSION

The key areas identified here cover the locations of almost 70% of the beaked whale records included in the database constructed for this analysis. They range from relatively small and discrete geographic areas, such as the Gully off Nova Scotia, to entire regions, such as the ETP or Southern Ocean and Antarctica. Such differences in scale reflect two factors. Firstly, they may reflect different levels of survey effort. For example, in the Gully, research has been specifically targeted at studying the northern bottlenose whales known to be found there (Whitehead *et al.*, 1997a), whereas for the Southern Ocean and Antarctic waters, most data come from wide-ranging surveys undertaken to estimate abundance of minke whales (Kasamatsu *et al.*, 1993; Branch and Butterworth, 2001). Furthermore, some key areas are based on strandings data, which at best provide only a low resolution view of patterns in beaked whale occurrence as they are heavily dependent on the prevailing conditions, with animals potentially travelling great distances before stranding (MacLeod, 2000); such data can thus only be used to identify very general areas of occurrence. Secondly, they may reflect real differences in distribution at different scales and in different oceans. For example, on a broad scale, there is a high abundance of beaked whales throughout the Southern Ocean and Antarctic (Branch and Butterworth, 2001). In other locations, beaked whale distribution is related to fine-scale factors with relatively low levels of occurrence outside key areas (e.g. in one part of the northeastern Bahamas, beaked whale distribution is closely tied to the presence of a marine canyon and few groups are encountered away from this specific location; MacLeod and Zuur, 2005). Further data are required to investigate whether there are specific fine-scale areas that beaked whales preferentially use within broad-scale areas and whether fine-scale areas are part of larger networks of areas of high beaked whale abundance. This is particularly important for key areas such as the Southern Ocean and Antarctic, for which current fine-scale knowledge is limited.

Applying the identification of key areas to beaked whale conservation

Identifying key areas is not an aim in itself but rather a way of providing a focus for appropriate assessment, mitigation and regulatory strategies. However, there is little available information appropriate on mitigation and regulatory strategies for some of the identified potential anthropogenic threats, especially related to noise. Determination of the mechanisms behind such threats will only be possible if many currently isolated fields begin to collaborate (Cox *et al.*, 2006). Current work aimed at understanding how naval sonars may result in mass strandings of beaked whales includes researchers working in areas as diverse as auditory anatomy, sound propagation, physical oceanographic

modelling, diving behaviour, ecology and pathology (Gisiner, 2003). A similar multi-disciplinary approach is required to determine whether other potential threats are real. For example, although some biologists may suspect that particular activities, such as over-fishing of preferred prey, adversely affect beaked whales in some regions, it will require input from a number of disciplines to confirm or deny this, and where appropriate develop and implement appropriate mitigation strategies. In the absence of conclusive knowledge of anthropogenic impacts and appropriate mitigation strategies, a precautionary approach should be implemented in key areas.

The marine environment is a dynamic system with major changes occurring over relatively short time periods that can affect species distribution and habitat preferences, e.g. in the ETP during El Niño-Southern Oscillation events (Lu *et al.*, 2001; Richards and Engle, 2001), an increasing North Atlantic Oscillation Index (Kroencke *et al.*, 2001) or changes in local water temperatures in northwest Scotland (MacLeod *et al.*, 2005). It is thus important to recognise that the identified key areas may not be (and probably are not) static entities. This is perhaps particularly important for key areas that cover relatively small, discrete areas and that are based on fine-scale data, where small geographical shifts in oceanographic conditions could result in local changes in beaked whale distributional patterns. Consequently, the key areas should be regularly monitored for changes in beaked whale distribution and occurrence. This information can then be used to increase the understanding of how key areas may change over time and with certain environmental changes, which can then be taken into account in future identification of key areas.

It is almost certain that further research will identify additional key areas as well as leading to the modification of existing ones. For example, a similar analysis carried out a decade ago would have identified only eight of the current key areas. Even in this study a number of other areas went close to fulfilling our criteria. From the strandings evidence and a limited number of sightings, the Aleutian Islands, particularly around Adak (51.9°N, 176.6°W), seem a likely future key area (Loughlin *et al.*, 1982; Walker and Hanson, 1999). However, more data, particularly on distribution at sea and the causes of a number of mass strandings of Stegneger's beaked whale (*M. stegnegeri*) on Adak (Walker and Hanson, 1999), are required. This reinforces the fact that absence of evidence should not be taken as evidence of absence. Simply because an area is not identified as a key area in this paper, it does not mean that beaked whales are not present, locally important or susceptible to anthropogenic impacts in other areas.

To identify or modify key areas requires the undertaking of dedicated research projects and surveys; many areas of the world remain unsurveyed, e.g. the eastern tropical Atlantic. However, undertaking dedicated surveys and research projects for oceanic species is complex, expensive and may take several years. In order to help focus this effort therefore, it would be valuable to use newly developed techniques of spatial modelling with the available data on beaked whale occurrence to predict areas of suitable beaked whale habitat (e.g. Hedley *et al.*, 1999; Cañadas *et al.*, 2005; IWC, 2006). These areas can then be the focus of dedicated surveys to confirm or deny the presence of beaked whales, as well as highlighting further areas where a precautionary approach to anthropogenic disturbance is warranted.

The use of key areas as proposed here combined with a spatial modelling approach should allow suitably precautionary conservation measures to be applied despite the relatively poor knowledge of beaked whales in many areas of the world, as well as focussing efforts to improve our knowledge.

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