Distribution and abundance of Cuvier's beaked whales in the Canyons of Southern Biscay

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ABSTRACT

Line transect boat-based surveys of the southern Bay of Biscay were carried out in June/July 2006-2008 inclusive. The target species was Cuvier's beaked whale (*Ziphius cavirostris*) and the aim was primarily to assess distribution and density of beaked whales in the Torrelavega Canyon, Cap Breton Canyon and southern continental slope. During the surveys, nine individual Cuvier's beaked whales were visually tracked and surface time data used as a measure of availability bias to correct density estimates. The highest corrected density of Cuvier's beaked whales was recorded in 2006 in the Torrelavega Canyon stratum; 0.132 animals/km^2 (0.23). This represents the greatest density currently recorded when compared with other published visual survey estimates from around the globe. Density was also high in the Cap Breton Canyon, but with lower densities recorded on the slope. The slopes of the canyons of the southern Bay of Biscay are an important habitat for beaked whales and their preferential distribution in these areas is likely linked to prey availability. Group sizes were also larger in the Canyons than along the slopes. Cuvier's beaked whales are particularly sensitive to some sources of anthropogenic noise and future activity in the area which has the potential to affect this species must be carefully mitigated.

CUVIER'S BEAKED WHALE, BAY OF BISCAY, LINE TRANSECT, DENSITY, CANYONS

INTRODUCTION

Beaked whales are the least known of cetaceans and for many species, the little data we have is from a few stranded specimens. There is particular concern about the effects of anthropogenic sound sources on beaked whales, particularly active sonar since several mass strandings have occurred concurrent with naval operations (Evans and Miller, 2004; Cox *et al*., 2006). Although the effects of sonar on cetaceans are not exclusive to beaked whales, they do appear to be particularly sensitive to it (e.g. Simmonds and Lopez-Jurado, 1991; Jepson *et al*., 2003). Cuvier's (*Ziphius cavirostris*), Blainville's (*Mesoplodon densirostris*) and Gervais (Mesoplodon europaeus) beaked whales are the most affected.

Cuvier's beaked whales are, by comparison to most beaked whale species, well known and are regularly recorded at sea in some locations and well documented in strandings records (Heyning, 1989). Mass strandings of this species have also been reported worldwide with 41 events between 1960 and 2003 (Brownell *et al.*, 2004; Taylor *et al.*, 2004). Some of the more recent events were concurrent with naval manoeuvres and use of active sonar in the Ionian Sea (Frantzis, 1998), the Bahamas (Balcomb and Claridge, 2001; Waring *et al.*, 2001) and Canary Islands (Degollada *et al.*, 2003). However, the documented mass strandings may represent only a proportion of the total number of animals potentially affected due to unrecorded stranding events or dead animals that never came ashore. Further data are required to improve our understanding of this species - its distribution, abundance and general ecology so we can more fully assess impacts. Without such data, designing effective mitigation measures to minimise anthropogenic effects may be compromised.

There is the opportunity to establish research sites in several places in North Atlantic waters where beaked whales occur regularly; the Bay of Biscay is one such location. Of the six beaked whale species occurring regularly in the North Atlantic (MacLeod, 2000), all have been recorded in the Bay of Biscay (Cresswell and Walker, 2001; Walker et al., 2001; Weir *et al.*, 2004; Vázquez *et al.*, 2004; Smith, 2010). Cuvier's beaked whales occur throughout the tropical and warm temperate oceans of the world and are generally considered the most widespread and abundant species within the family Ziphiidae. Yet surprisingly, there are very few places where they can be encountered consistently within a given area. The southern Bay of Biscay is arguably one of the most reliable of the more accessible locations in the world to encounter this species year-round (Smith, 2010). The bathymetry of the Bay of the Biscay is likely to be an important factor determining beaked whale occurrence in these waters.

Annual beaked whale surveys were carried out in the southern Bay of Biscay canyons during June/July in 2006, 2007 and 2008. The primary aim of the surveys was to collect fine scale baseline data on distribution and abundance of Cuvier's beaked whale (and other cetaceans) in the Torrelavega and Cap Breton Canyons and southern continental slope. Secondary objectives were to collect behavioural and photo-ID data during encounters. Single platform line transect visual and acoustic surveys[1] were carried out from the 60 foot ketch "Blue Fin of Hamble". Single platform distance sampling data will generate biased estimates of abundance for many cetacean species, primarily because the theory assumes, amongst other things, that detection of cetaceans on the trackline is certain (g(0)=1). Violation of this assumption leads to negatively biased abundance estimates. Animals are missed on the transect line for two reasons; i) they were underwater at the time of the survey (availability bias) or ii) they were at the surface but missed by the observers (perception bias). Availability bias is particularly acute for beaked whales. During this survey, information on average surface times was collected and used as a crude correction for availability bias. We were unable to account for perception bias.

This paper reports on the analysis of the visual survey data and shows that the density of Cuvier's beaked whales in the southern Bay of Biscay is currently the highest recorded globally when compared with the existing published visual survey estimates.

METHODS

Field methods

Boat based surveys were carried out on the following dates: i) 2nd – 18th July 2006; ii) 2nd – 21st July 2007 and iii) 28th June - 18th July 2008. The 2006 and 2008 surveys were coordinated by Organisation Cetacea (ORCA) and covered two strata in the southern Bay of Biscay: Torrelavega Canyon northwest of Santander and the Cap Breton Canyon directly east of Sanatander (Figure 1). The 2007 survey was coordinated by SeaWatch and the survey strata covered the shallower slope waters to the coast (Figure 1), with some overlap primarily with the 2008 area. The survey transects were designed using the software DISTANCE (Thomas et al. 2009) and employed a zigzag sampler.

Standard observation methods were used throughout to collect distance sampling data. Two observers were situated on the starboard and port side of the ship looking from abeam of the boat, to 5° over the transect line. A data recorder collected sightings and effort data real-time using the software Logger (IFAW, 2001) (2006 and 2008 surveys) or similar program (2007). The angle board was located on top of the cockpit and the two observers were placed either side of it for ease of use and communication between themselves and the data recorder. Radial distance to sightings was recorded using 7x50 reticle binoculars or by eye. Observers were rotated every half hour through observation, data recorder and rest positions. The maximum duration on watch was 60 minutes. Surveying was only carried out in Beaufort seastate 4 or below with good visibility.

Data on diving behaviour were collected whenever possible during beaked whale encounters. Line transect effort was stopped and Cuvier's beaked whales approached for visual tracking and photo-ID. Diving behaviour was recorded using specially created fields on the sightings and re-sightings forms of the Logger database. Each time the animals started a dive or surfaced/re-surfaced observers shouted "Dive" or "Surface" and the data recorder triggered a new re-sighting page and checked a yes/no box in the fields "dive" or "surface". As both sightings and re-sightings forms were automatically time-stamped when opened, it allowed dive times and surface periods to be calculated.

Analysis

All analyses were carried out using the DISTANCE software (Thomas *et al.,* 2009) and abundance was estimated using the standard equation:

$$\hat{N} = \mathrm{A} \times \frac{n \times s}{2L \times esw \times g(0)}$$

Where A is the survey area, n is the number of observations, s is the mean group size, L is the total length of transect sampled, esw is the effective strip half-width and $g(0)$ is the detection function at zero perpendicular distance. Assuming that g(0) is unity would introduce serious bias in to the estimates of abundance for beaked whales because of their prolonged dive periods. This parameter is a function of both availability and perception bias. Density estimates were corrected for availability bias using an estimate of mean surface time generated from surface and dive data collected during encounters in 2006 and 2008. The proportion of time spent at the surface (*ST*) was estimated from:

[1] The acoustic data are yet to be processed.

$$ST = \frac{E(sf)}{[E(sf) + E(d)]}$$

Where *E(sf)* is the average length of a surfacing and *E(d)* is the average length of a dive for all animals sampled (adapted from Forcada *et al*., 2004).

Due to limited sample sizes, the detection function was generated by pooling beaked whale sightings for all years. Half-normal and hazard rate models with cosine and polynomial adjustments were fitted. The best model was judged on the visual fit of the data, Goodness of fit statistics and the Akaike's Information Criteria. Data were too sparse to allow fitting of covariates. The effect of group size on the detection probability was tested by fitting a regression of the log of group size against detection probability. When estimating abundance, the mean from the regression was used over the mean observed group size if significant (α =0.15).

The common detection function was then used to estimate the density and abundance of Cuvier's beaked whale and 'beaked whales' for each year. The 'beaked whale' category included Cuvier's, Sowerby's and unidentified beaked whales. Uncorrected (D_{UNCOR}) and corrected (D_{COR}) (using the surface time correction for availability) density and abundance estimates are presented.

Variance of the uncorrected density estimates was calculated using the method of Innes et al. (2002) which is based on the empirical variance of the estimated density between samples. For corrected estimates, additional variance due to the surface time correction factor was accounted for; the variance of corrected density was estimated using the delta method (Buckland *et al*., 2001):

$$Var(D_{COR}) = \{(D_{UNCOR})^2 \times [Var(D_{UNCOR})]^2 + (ST)^2 \times [Var(ST)]^2\}$$

RESULTS

The total survey effort over the three years was 2,965km (Table 1). Over the three surveys, 39 groups of beaked whales were recorded whilst on survey effort amounting to 76 individual whales (Figure 2). Cuvier's beaked whales accounted for the majority of sightings, amounting to almost 70% of beaked whale records. Beaked whales were distributed mainly in the south of the 2006 survey area (Torrelavega Canyon); limited to the north east slope of Cap Breton canyon in 2007; and throughout a central belt of the 2008 survey area. In all cases, sightings tended to occur in water depths of 1000-4000m.

For density estimation, a detection function was fitted to all beaked whales sightings using a half-normal key function (Figure 3: Detection function for perpendicular distance data to beaked whale sightings recorded during July surveys in 2006 -2008. The function is fitted using a half normal key following truncation at 800m. n= 34 observations.) applying a right truncation distance of 800m, leaving a sample size of 34 sightings. All data were used up to and including Beaufort seastate 4. The limited sample size meant that only perpendicular distance was modelled in the detection function and it was not possible to fit other covariates, such as sea state and swell height. This detection function was then applied to two subsets of the data; Cuvier's beaked whale (n = 25) and all beaked whales (n=34).

Data from visually tracked animals for a single or multiple complete dive cycles (surface and dive) were available for 9 animals in 2006 (75% of sightings) and 6 animals in 2008 (67% of sightings). The mean proportion of time individuals spent at the surface ranged from 0.11 to 0.45. Over all individuals, the average was 0.22 (se = 0.03) and this was used as a correction factor for "availability" (the short comings of this approach are discussed later).

Expected cluster size was used in the analysis and was greater in 2006 and 2007, compared with 2008 (Table 2). Density of Cuvier's beaked whales is summarised in Table 2. Estimates for the 'All beaked whales' group are given in Table 3. The density of Cuvier's beaked whales was greatest during 2006 when the survey covered the area of the Torrelavega Canyon; corrected density was 0.132 (CV = 0.23) animals/km^2. The lowest densities were recorded in 2007 (0.041 n/km^2, CV = 0.73) when the survey area comprised the shallower slope and continental shelf: however, this could have been an artefact of poorer sea conditions during this survey compared to the other surveys. The density of "all beaked whales" followed the same pattern.

These estimates are compared to others from visual surveys currently available in the published literature for the North Pacific and North Atlantic (Table 4).

DISCUSSION

Cuvier's beaked whales are present in high densities in the southern Bay of Biscay. Density was particularly high during the 2006 survey of the Torrelavega Canyon. The affinity of beaked whales for areas with canyons has been relatively well documented (Hooker *et al.*, 2001; Waring *et al.*, 2001; Claridge, 2006; this meeting SC/63/SM2). The corrected density estimate for Cuvier's beaked whales in the Torrelavega Canyon in 2006 is currently greater than any other published regional visual survey estimates in the North Pacific and North Atlantic, suggesting the habitat of this area is high quality for this species.

The only other estimate of beaked whale density in the Bay of Biscay comes from the CODA survey in 2007; the density of a "beaked whale" group, comprising Cuvier's, Sowerby's and Northern Bottlenose whales was 0.017 animals/km^2 (CV= 0.45) (Macleod *et al.,* 2009). CODA was a large scale shipboard survey of waters beyond the European continental shelf and therefore, localised effort was low. Estimates for beaked whales were also not corrected for g(0) and so are likely to be negatively biased. If one corrects for availability using the value of 0.22 used in this study, then the corrected density compares well with those presented in this paper, although is considerably less than the estimate for the Torrelavega Canyon surveyed in 2006. We also recorded larger groups in the 2006 and 2008 surveys which had greater coverage in the Canyons. The differences in density are likely due to a preference of beaked whales for continental slopes and canyon areas. The area surveyed during CODA covered a significant region of the Bay of Biscay abyssal plain. Similarly, we attribute the differences in density between the 2006, 2007 and 2008 surveys in this study to be due to differences in the depth profiles of the survey areas and therefore suitability of the habitat for Cuvier's rather than inter-annual differences.

The Cap Breton Canyon has been previously surveyed by Vázquez *et al.* (2004). They encountered high numbers of Cuvier's beaked whale (0.04 sightings/km) during visual surveys in 2003, but density estimates were not derived. The only other North Atlantic area currently to estimate high Cuvier's beaked whale density is in the Alboran Sea (Canadas *et al.* this meeting). The authors report a density of 0.059animals/km^2 using a correction for availability of 0.306. Applying this correction factor to the Torrelavega Canyon estimate gives a density of Cuvier's beaked whales of 0.094animals/km^2 which is over one-and-a-half times greater. This estimate of availability was derived from a time-depth recorder deployed on a single Cuvier's beaked whale in the Ligurian Sea (Oedekoven *et al.* 2009).

On a global scale, there are no published estimates of higher densities of Cuvier's beaked whales from visual surveys (Table 4). Density estimates of Baird's beaked whale from the eastern slopes of Japan show high tens of animals per 1000km^2 (cited in Barlow et al., 2006), which is comparable to densities of Cuvier's in the southern Biscay region.

The density estimates presented are likely still biased due to a number of factors. Firstly, perception bias could not be accounted for and this would have a negative effect on g(0). Given that observations were made from a relatively low platform and in sea states up to Beaufort 4, we would expect that perception bias would be quite high which would ultimately increase density estimates. Our estimate of availability is likely to be an overestimate due to its basis on observed dive cycles that relied on reliable tracking of individuals. Observers were able to monitor sightings and re-sightings for a series of relatively short dives (which in some cases, tracking lasted for an hour). Short, relatively shallow dive series have been documented in Cuvier's beaked whales in Hawaii and is thought to be an important preparation behaviour for deep dives, rather than a recovery phase from a previous deep dive (Baird *et al.*, 2006). Tracking ceased when the animal was lost or left when it was assumed that it was on a deep dive (submerged for >30 minutes). Therefore, the surface times do not represent those long, deep dives which are known to occur in other areas: for example, dives in excess of 50 minutes are recorded at least once every 2 hours in Hawaii (Baird *et al.*, 2006). Taking the above into account, the value of g(0) for these surveys was likely lower than our estimate of availability (0.22) alone. Estimates of g(0) from other regions range from 0.23-0.84 and the g(0) of 0.23 (Ferguson and Barlow, 2001) has been widely applied to correct abundance estimates for this species of the U.S west coast and Hawaii (Table 4).

Any future activity in the southern Biscay which will use active sonar (or other potentially damaging acoustic source) has the potential to have a major impact on the Cuvier's beaked whales of this region. Perhaps high risk activities have already taken place in this region with no apparent affect; however, a lack of carcasses on the shore is not a reliable measure of impact. Many factors affect whether a carcass will strand (e.g. distance of suitable habitat from shore) and be detected (e.g human population density along the coast) (Faerber and Baird, 2010). The best mitigation of high-risk activities would be to avoid this area of globally significant density of Cuvier's beaked whales. Further research in the southern Bay of Biscay should be promoted. The series of boat based surveys presented in this document are evidence of a very high density of animals that can be approached and successfully tracked. Telemetry studies would greatly enhance knowledge of behavioural ecology of this species in the area and would further our knowledge considerably.

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TABLES AND FIGURES

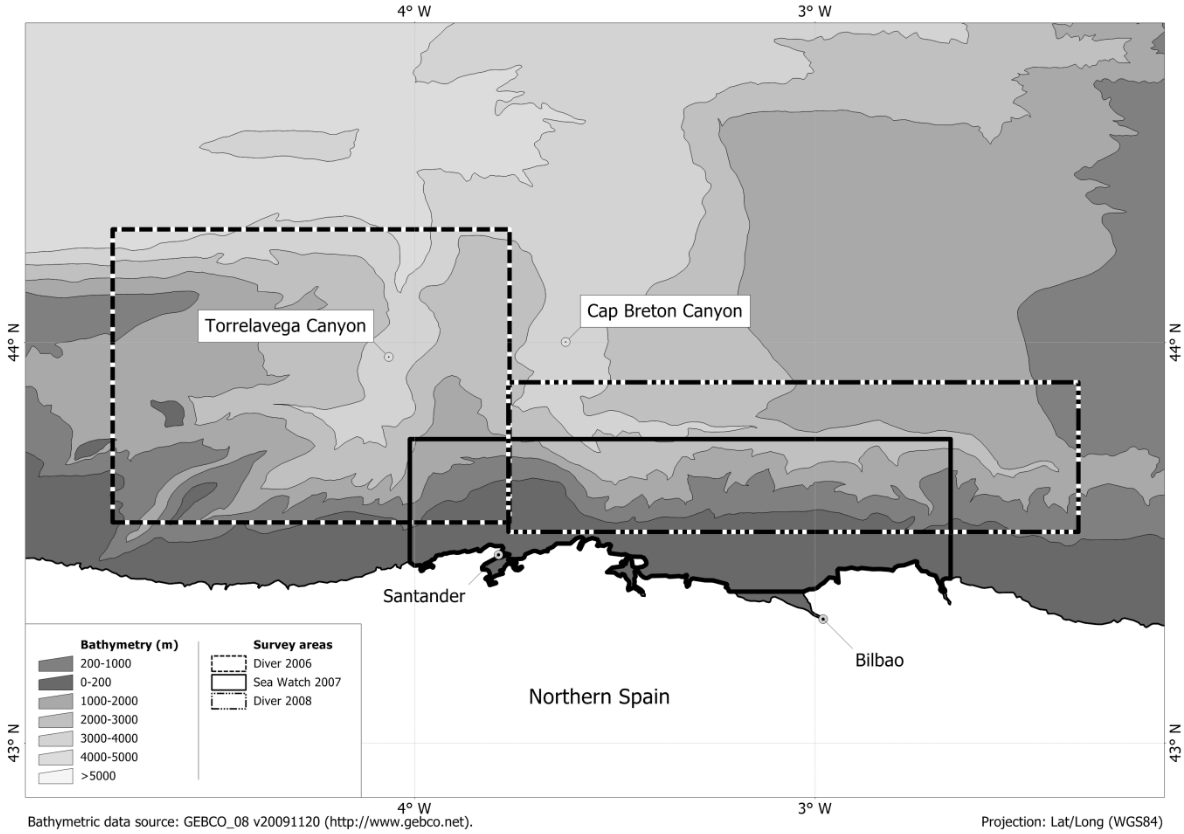

Figure 1: Survey areas and transects in the southern Bay of Biscay off northern Spain.

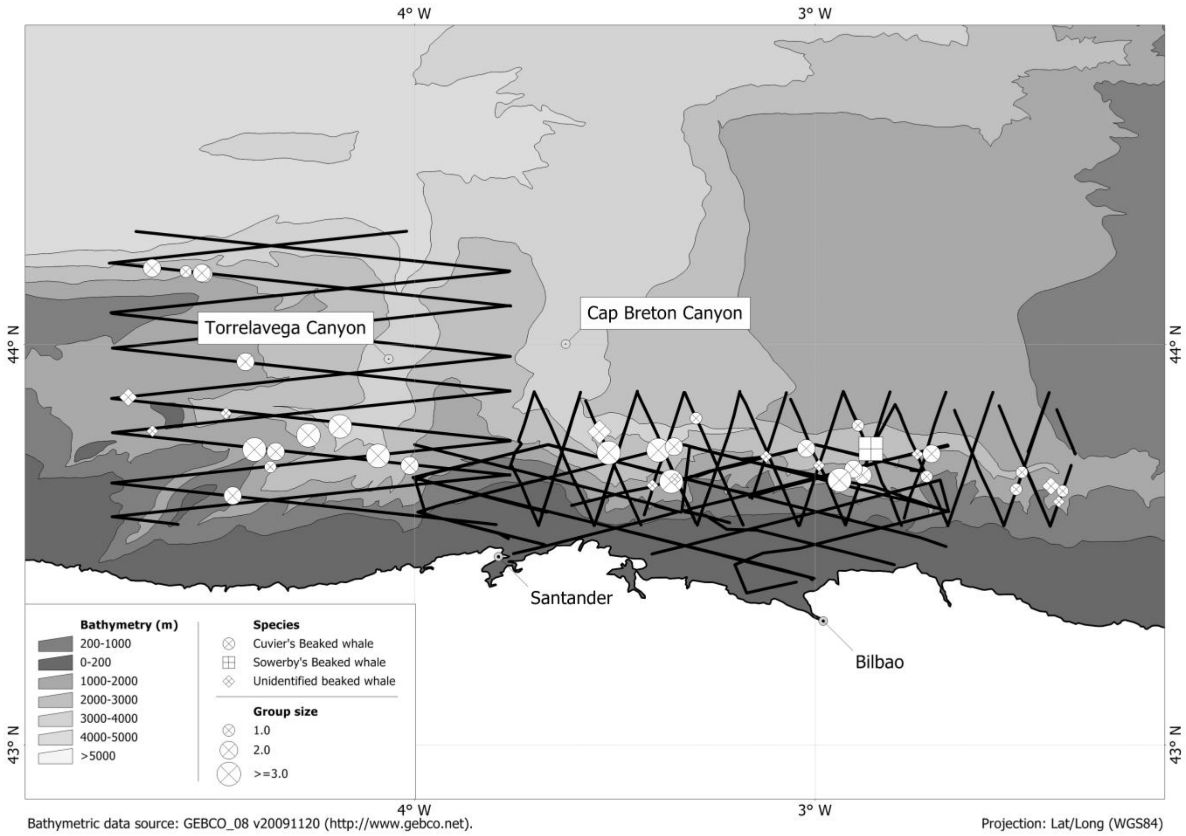

Figure 2. Distribution of beaked whale sightings recorded during the three surveys, 2006-2008.

Figure 3: Detection function for perpendicular distance data to beaked whale sightings recorded during July surveys in 2006 -2008. The function is fitted using a half normal key following truncation at 800m. n= 34 observations.

Table 1: Summary of survey effort during each survey and numbers of beaked whales sightings. CB = Cuvier's beaked whale; SB = Sowerby's beaked whale and UB = Unidentified beaked whale.

Year	Area (km^2)	Effort (km)	CB sights (Individuals)	SB sights (Individuals)	UB sights (Individuals)
2006	6,457	953	12 (29)	0	3(4)
2007	3,932	1,212	6 (16)	0	3 (4)
2008	4,312	800	9 (13)	2 (6)	4 (4)
Total	14,701	2,965	27 (58)	2 (6)	10 (12)

Table 2: Density estimates of Cuvier's beaked whales (animals/km^2) by year. Corrected estimates use an estimate of availability of 0.22 (SE = 0.03)

				Corrected for availability bias		
Year	Cluster size (se)	Density (n/km) (CV)	Abundance [95%CI]	Density (n/km) (CV)	Abundance (CV)	n/1000km^2
2006	2.4 (0.43)	0.029 (0.37)	185 [88-389]	0.132 (0.23)	841 (0.23)	131
2007	2.4 (0.00)	0.009 (0.52)	37 [13-102]	0.041 (0.73)	168 (0.23)	41
2008	1.5 (0.43)	0.014 (0.50)	61 [23-161]	0.064 (0.47)	277 (0.23)	64

Table 3: Density estimates of all beaked whales (animals/km^2) by year. Corrected estimates use an estimate of availability of 0.22 (SE = 0.03)

				Corrected for availability bias		
Year	Cluster size (se)	Density (n/km) (CV)	Abundance [95%CI]	Density (n/km) (CV)	Abundance (CV)	n/1000 km2
2006	2.2 (0.29)	0.03 (0.32)	210 (110-403)	0.136 (0.22)	955 (0.22)	136
2007	2.0 (0.32)	0.01 (0.40)	49 (22-109)	0.045 (0.66)	223 (0.66)	45
2008	1.7 (0.41)	0.02 (0.46)	96 (39-236)	0.091 (0.33)	436 (0.33)	91

Table 4: Published global density estimates for Cuvier's beaked whales, highlighting the importance of the Biscay region for this species.

Area	Year	Beaufort range	Density (n/1000km^2) (CV)	Bias correction?	Source [2]
North Atlantic					
Bay of Biscay	**2006-2008**	**0-4**	**45-136 (0.23-0.73)**	**Availability = 0.22**	**Current paper. Macleod et al 2011**
Alboran Sea			59 (NA)	Availability = 0.306	SC/63/SM ? (Canadas et al.)
US NE Coast	1978-1982	0-3	0.1 (0.94)	None	Winn, 1982
Gulf of Mexico	1991-1994	0-5	0.1 (0.50)	None	Hansen et al. 1995
Gulf of Mexico	1996-2001	0-4	0.2 (0.47)	None	Mullin and Fulling, 2004
Gulf of Mexico	1992-1994	0-3	0.1 (0.71)	None	Mullin et al. 2004
Gulf of Mexico	1996 - 1999	0-4	0.3 (0.83)	None	Mullin and Hoggard, 2000
North Pacific					
Eastern Tropical Pacific	1986-1990	0-5	1.0 (0.27)	None	Wade and Gerrodette, 1993
California	1991	0-2	2.0 (0.82)	g(0) = 0.84	Barlow, 1995
Eastern North Pacific	1986-1996	0-2	3.6 (NA)	g(0) = 0.23	Ferguson and Barlow, 2001
US West coast	1996 & 2002	0-2	1.6 (0.68)	g(0) = 0.23	Barlow, 2003
Hawaii	2002	0-2	6.2 (1.43)	g(0) =0 0.23	Barlow, 2006

[2] For reference see Barlow et al. 2006.