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CETACEANS OFF GABON BASED ON A 2011 SIGHTING SURVEY, WITH A PRELIMINARY DENSITY ESTIMATE OF THE HUMPBACK WHALE *MEGAPTERA NOVAEANGLIAE*

Samba T. DIALLO[1], Aboubacar SANE[1], Thomas NELSON[2], Taiki KATSUMATA[3] and Takashi HAKAMADA[3]*

[1] *Centre National des Sciences Halieutiques de Boussoura (CNSHB), 814 Rue MA 500, Corniche Sud Madina, Boussoura Port, Conakry 224, Guinea*
[2] *Department of Fisheries (DOF). Ministry of Agriculture, Fisheries, Physical Planning, Natural Resources and Co-operatives (MAFPPNRC) Conway Post Office, Castries, LC04 30, Saint Lucia*
[3] *Institute of Cetacean Research, 4–5 Toyomi-cho, Chuo-ku, Tokyo 104–0055, Japan*
**Corresponding author: hakamada@cetacean.jp*

Abstract

Results of a cetacean sighting survey in coastal Gabon waters from September 4 to 9, 2011 are reported. Four whale species humpback (30 schools/191 individuals), Bryde's (1 school/2 individuals), sei (1 school/6 individuals), and sperm (2 schools/2 individuals), and 3 species of dolphin (pantropical spotted (1 school/150 individuals), Atlantic spotted (1 school/40 individuals) and bottlenose (1 school/25 individuals)) were observed over 232.1 nm of transect lines (26% of planned transects, covering 878.0 nm). Based on these survey data, using distance sampling methods, we estimate the density of humpback whales in this region to be 0.481 individuals/nm^2 (CV = 0.477).

Key words: Gabon, humpback whale, distance sampling, density estimation, line transect.

Humpback whales *Megaptera novaeangliae* occur worldwide in all major oceans (Clapham, 2018). The Scientific Committee of the International Whaling Commission (IWC/SC) identified seven breeding stocks (A–G) of this species in the Southern Hemisphere (IWC, 2005), with waters off Gabon including part of stock B. From 1912–1930, 7,883 humpback whales were landed at whaling stations in Gabon (Harmer, 1928; Best, 1994), and a further 7,080 animals were landed in 9 whaling seasons between 1934 and 1959 (Budker and Collignon 1952; Budker 1952, 1953; Budker and Roux 1968; Weir, 2010). While commercial humpback whaling in the Southern Hemisphere was banned by the IWC in 1963 (IWC, 2011), after more than 50 years it is thought that stocks of this species may have recovered. A comprehensive assessment of Southern Hemisphere humpback whales was completed in 2015. An assessment model was conducted then using abundance estimates by mark-recapture methods provided in Collins *et al.* (2010); the depletion level (i.e., abundance per initial population size) of the humpback whale breeding stock off Gabon was estimated to be 74% in 2015 (IWC, 2016).

Three cetacean sighting surveys have been completed in COMHAFAT (La Conférence Ministérielle sur la Coopération Halieutique entre les Etats Africains Riverains de l'Océan Atlantique) coastal zone waters. The first cetacean sighting survey in Gabon coastal waters occurred in 2011; a second survey took place in the Gulf of Guinea in 2013, covering the Côte d'Ivoire, Ghana, Togo and Benin (Diallo and Bamy, 2013). A third survey was conducted in coastal waters of Guinea, Sierra Leone and Liberia in 2018 (Diallo *et al.*, 2018). A fourth proposed (2019) survey was scheduled for coastal waters off Guinea, but it has yet to be done. During the 2019 IWC/SC68a meeting in Nairobi, Kenya, the plan for this fourth survey in the COMHAFAT coastal zone was presented. The IWC Standing Working

Group on Abundance Estimates, Status of Stocks, and International Cruises (ASI) encouraged that abundance estimates of cetacean species sighted in the COMHAFAT coastal zone be presented to the future IWC/SC meeting to determine how they could be used for the Revised Management Procedure (RMP) or for other cetacean studies in this region (IWC, 2020). For this reason, we report hitherto unpublished estimates of humpback whale abundance data from the 2011 survey off Gabon.

The 2011 survey was conducted during the dry season in waters off Gabon (when rain is scarce and wind is weak). Because many cetacean species migrate into waters off Gabon during the austral winter (Weir, 2010), we performed this survey during this period. The main objective was to obtain information on the abundance and distribution of cetaceans in the coastal zone of Gabon (Diallo and Bamy, 2013). The survey was performed by the Centre National des Sciences Halieutiques of Boussoura (CNSHB) under the auspices of COMHAFAT, with collaboration from some African fisheries institutions and fisheries research centers, such as the Direction Générale des Pêches (DGP) in Gabon, Centre de Recherches Océanologiques (CRO) of Abidjan in Côte d'Ivoire, Institut Mauritanien de Recherche Océanographique et des Pêches (IMROP) of Nouadhibou in Mauritania, Centre de Recherche Océanographique de Dakar Thiaroye (CRODT) of Dakar in Senegal, Direction des Pêches (DP) of Cotonou in Benin, Marine Fisheries Research Division (MFRD) of Tema in Ghana, Fisheries and Oceanography Research Station (SRHOL IRAD) of Limbé in Cameroon, and the Center for Applied Fisheries Research (CIPA) of Bissau in Guinea-Bissau.

The *N/O General Lansana Conté*, a research vessel of Guinean nationality, 29.93 m in length, 3.25 m in draught, of 1400 CV horsepower and 198 GRT (Fig. 1), was used for the survey. Further survey details are provided in Diallo and Bamy (2013). A 10-day survey period was scheduled in September 2011, as per the itinerary shown in Table 1.

The study area was in the Gabonese EEZ including the isobaths from 200 m to 1,000 km, and excluded shallow waters and areas around oil fields. Six survey blocks were identified (left panel, Fig. 2) comprising three offshore (ON, OM, OS) and three coastal (CN, CM, CS) blocks. Within blocks, zigzag track lines of 878.0 nm total length were set (right panel, Fig. 2). Survey participants included 10 vessel crew and 9 research staff; 2 Guinean researchers conducted the survey, with researchers from each of 6 African countries (1 from each of Mauritania, Senegal, Ghana, Benin, and Togo, and 2 from Gabon) also participating. The cruise leader, Samba Diallo, entered data onto a computer during the survey; other scientists helped identify schools of cetaceans and count numbers of individuals.

The survey used a line-transect method (Burnham *et al.*, 1980) authorized by the Scientific Com-

Fig. 1. The *N/O General Lansana Conté* used for COMHAFAT cetacean sighting surveys.

Table 1. Itinerary of the 2011 cetacean sighting survey in Gabon coastal waters.

Date	Event
August 29	Vessel left Conakry to Libreville
August 28–30	Participants arrived in Libreville
August 31	Pre-survey meeting was held in Libreville
September 2	Vessel arrived at Libreville
September 3	Vessel left Libreville to survey area
September 4	Survey was started
September 9	End of the survey
September 10	Vessel arrived in Libreville
September 11	Vessel left Libreville to Conakry
September 12	Post-survey meeting was held in Libreville
September 13–14	Participants left Libreville
September 14	Vessel arrived at Conakry

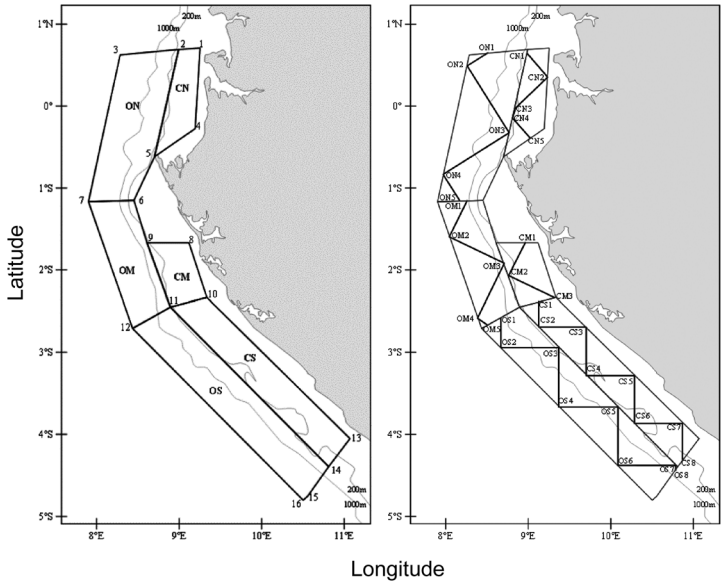

Fig. 2. Gabon coastal water research areas: 2011 survey blocks conducted by COMHAFAT (left panel) and survey zig-zag track lines of 878.0 nm length set in survey blocks (right panel) (after Diallo and Bamy, 2013).

mittee of the IWC, following procedures and protocols in the requirement and guidelines for sighting surveys (IWC, 2012). Surveys occurred during daylight from 30 min after sunrise to 30 min before sunset, in good weather conditions (Beaufort scale ≤4, visibility >2 nm). A normal closing mode survey was performed for all encountered cetacean species; for further details of sighting procedures see Diallo and Bamy (2013). Angles to sightings were measured using angle boards situated in front of observers. To calibrate the distances to and angle measurements of sightings, distance and angle measurement experiments were performed during the survey (to adjust measurement error if necessary).

During the survey, sighting effort and weather data were recorded. All data, including photographs belong to the COMHAFAT, with copies stored at the CNSHB in Guinea, and the Fisheries Resources Institute, Japan Fisheries Research and Education Agency, in Japan.

To estimate humpback whale density, we used data for 13 primary (ship on-effort) sightings for this species, and effort data. For detection function estimation, conventional distance-sampling methods were used, including multi-covariate distance sampling, where detection on the track line is assumed as certain (i.e. $g(0)=1$). The covariate to be considered for possible inclusion in the detection function

is school size. Missing values for other candidate covariates (such as Beaufort scale and visibility) precluded our considering them in detection functions.

We used the Multiple Covariate Distance Sampling (MCDS) Engine in the mrds package in R for calculations (Thomas *et al.*, 2010). The Hazard rate and Half normal models are fitted as candidate models for the detection function. The full model of the detection function is provided by:

$$\text{Hazard rate: } g(x,z) = 1 - \exp\left[-\left\{ x \Big/ a \exp(Size) \right\}^{-b} \right] \tag{1}$$

$$\text{Half normal: } g(x,z) = \exp\left[-x^2 \Big/ 2a^2 \exp\{2(Size)\} \right] \tag{2}$$

where x is the perpendicular distance from the track line to the sighting, z is a vector of covariates (i.e., *Size*), a ($a>0$) and b ($b\geq 1$) are coefficients to be estimated, and *Size* is observed school size.

Density estimation is the second step used in the distance-sampling method. The analytical method follows that of Buckland *et al.* (2015). For analysis we assumed that all schools of cetaceans on the track line were detected. Density and its variance were estimated based on a Horvitz–Thompson like estimator of abundance, as expressed in equations (3) and (4), respectively:

$$D = \frac{1}{2WL} \sum_{i=1}^{n} \frac{s_i}{p(x_i, z_i)} \tag{3}$$

where D is the density estimate, W is the truncation distance, L is the searching effort, s_i is the size for ith school, and $p(x_i, z_i)$ is the probability of detection at a perpendicular distance x_i and covariate z_i.

$$\text{var}(D) = \left(\frac{1}{2WL} \right)^2 \left\{ \frac{1}{L(K-1)} \sum_{k=1}^{K} l_k \left(\frac{P_{Ck}}{l_k} - \frac{P_C}{L} \right)^2 + \sum_{j=1}^{r} \sum_{m=1}^{r} \frac{\partial P_C}{\partial \theta_j} \frac{\partial P_C}{\partial \theta_m} H_{jm}^{-1}(\theta) \right\} \tag{4}$$

where K is the number of transect, l_k is searching distance in kth transect, P_{Ck} is the abundance estimate in the covered region on the kth transect, P_C is the abundance estimate in the covered region, and $H_{jm}^{-1}(\theta)$ is the jmth element of the inverse of the Hessian matrix of detection function with respect to the vector of the coefficients θ.

Akaike information criterion (AIC) values were compared to select the best model to estimate the probability of a school being detected $p(z_i)$ given the covariate z_i, which is expressed by the following equation (5) using the detection function $g(x, z_i)$ (see equations (1) and (2)). The detection function with the minimum AIC is selected as the best model among the candidate models.

$$p(z_i) = \frac{1}{W} \int_0^W g(x, z_i)\, dx = \frac{1}{W} \hat{f}\left(0 | z_i\right) \tag{5}$$

The 2011 survey in coastal waters of Gabon covered 232.1 nm over 6 days—only 26% of the planned searching distance. Although 10 survey days had been initially scheduled, only the ON, CN and CM blocks out of 6 blocks could be covered within available time (Fig. 3). During this survey, 30 schools of humpback whales (191 individuals), 2 schools of sperm whales (*Physeter macrocephalus*) (both with 1 ind.), and 1 school of each of Bryde's (*Balaenoptera edeni*) (2 ind.) and sei (*B. borealis*) (6 ind.) whales, and 1 school of pantropical spotted (*Stenella attenuata*) (150 ind.), 1 school of Atlantic spotted (*S. frontalis*) (40 ind.), and 1 school of bottlenose (*Tursiops truncatus*) (25 ind.) dolphins were detected (Table 2). Sighting positions for (a) humpback whales, (b) Bryde's, sei, and sperm whales, and (c) dolphins are shown in Fig. 3. No feeding behavior was observed during the survey.

The best model of estimated detection function fitted to the relative frequency of detected schools by perpendicular distance intervals as a function of perpendicular distance from the track line to a humpback whale sighting using 2011 survey data is depicted in Fig. 4. A density estimate of

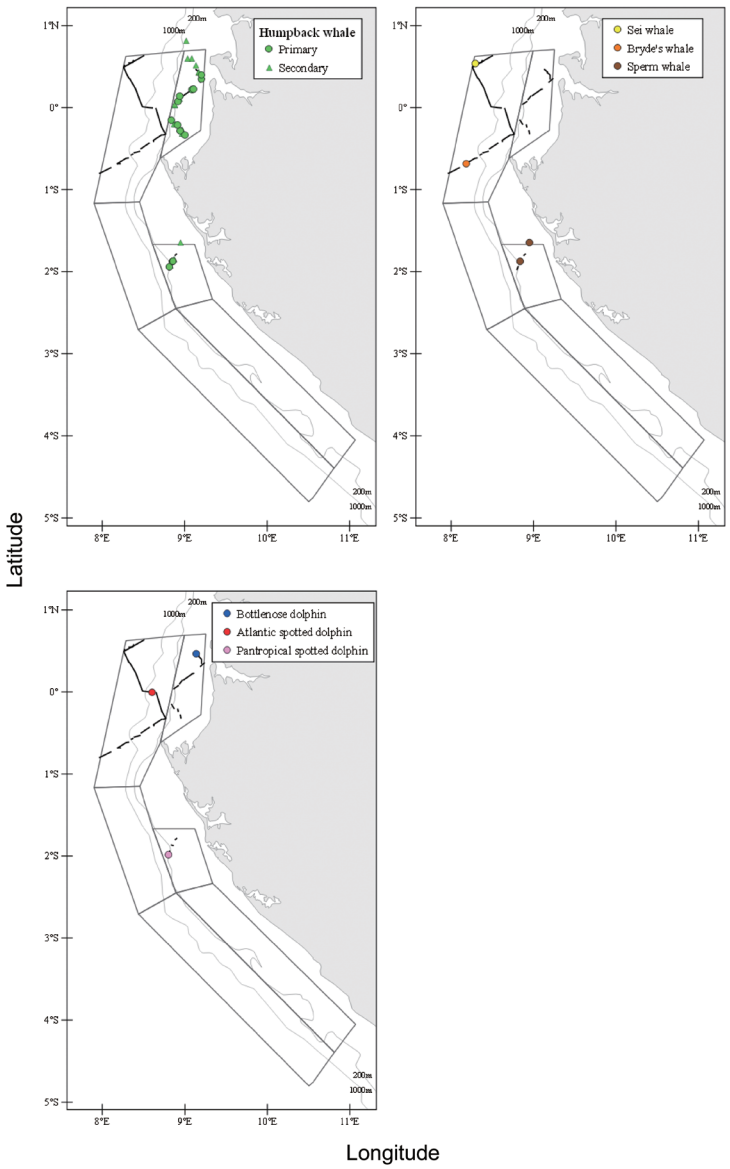

Fig. 3. Map of the 2011 survey area, blocks, line transects, and sighted schools of humpback whales (upper left panel), Bryde's, sei and sperm whales (upper right panel), and dolphins (lower panel).

Table 2. Primary and secondary sightings during the 2011 cetacean sighting survey.

Species name	Primary		Secondary		Total	
	Sch.	Ind.	Sch.	Ind.	Sch.	Ind.
Humpback whale	13	50	17	141	30	191
Sperm whale	1	1	1	1	2	2
Sei Whale	0	0	1	6	1	6
Bryde's whale	1	2	0	0	1	2
Pantropical spoted dolphin	0	0	1	150	1	150
Atlantic spotted dolphin	1	40	0	0	1	40
Bottlenose dolphin	1	25	0	0	1	25
Unidentified whale	2	2	6	13	8	15
Unidentified dolphin	3	15	1	10	4	25

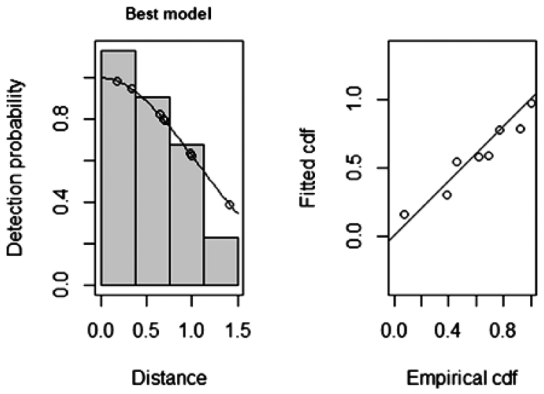

Fig. 4. Plot of the best model of estimated detection function fitted to relative frequency of schools as a function of perpendicular distance (nm) from the track line to a humpback whale sighting based on 2011 survey data. Cdf in the caption for the right panel is the abbreviation for cumulative distribution function.

0.481 ind./nm^2 (CV=0.477) from this model has a low AIC of 11.437. Branch (2011) estimated humpback whale abundances in feeding grounds in Antarctic waters south of 60°S during the austral summer to be 4.36×10^{-5} ind./nm^2 (CV=0.53) in 1992/93 between 0° and 40°E, and 2.55×10^{-4} ind./nm^2 (CV=0.75) in 1996/97 between 30°W and 0°. Branch (2011) considered that estimates of abundance in breeding stock B were greater than in the assumed corresponding feeding area (20°W–10°E) in Antarctic waters because humpback whales in their southern migration migrated to waters north of 60°S. It is therefore likely that most humpback whales from this breeding stock do not migrate as far south as 60°S to reach that area covered by the International Decade of Cetacean Research/Southern Ocean Whale and Ecosystem Research Programme (IDCR/SOWER) surveys. Japanese Sighting Vessel (JSV) data identify a high density area north of 60°S (Miyashita *et al.*, 1995), with many sightings of this species in 2005/06 during the IWC SOWER survey (Ensor *et al.*, 2006). Another possibility is that animals in breeding stock B migrate to a different longitudinal sector, supported by genetic evidence that breeding stock B does not differ significantly in Areas II and III, in longitudinal sectors 60°W–70°E (Loo *et al.*, 2011).

Because more humpback whales were sighted in CN and CM than in ON blocks, more survey effort could be allocated to coastal as opposed to offshore blocks in future surveys (to more accurately estimate humpback whale abundance). Buckland *et al.* (2015) and the IWC (2012) suggested allocating increased effort to known high density strata. If more primary sightings occur in future COMHAFAT surveys, further analyses of abundance estimates could be performed for other species from the 2011 survey data (i.e., sei, Bryde's and sperm whales, and pantropical spotted, Atlantic spotted, and bottlenose dolphins).

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