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ORIGINAL PAPER

A first estimate of sea turtle bycatch in the industrial trawling fishery of Gabon

Paolo Casale[1] · Gaspard Abitsi[2] · Marie Pierre Aboro[3] · Pierre Didier Agamboue[2] · Laureen Agbode[2] · Nontsé Lois Allela[4] · Davy Angueko[4] · Jean Noel Bibang Bi Nguema[5] · François Boussamba[3] · Floriane Cardiec[2] · Emmanuel Chartrain[2] · Claudio Ciofi[6] · Yves Armand Emane[4] · J. Michael Fay[7] · Brendan J. Godley[8] · Carmen Karen Kouerey Oliwiwina[2] · Jean de Dieu Lewembe[4] · Donatien Leyoko[4] · Georges Mba Asseko[5] · Pulcherie Mengue M'adzaba[4] · Jean Hervé Mve Beh[9] · Chiara Natali[6] · Clauvice Nyama-Mouketou[5] · Jacob Nzegoue[2] · Carole Ogandagas[4] · Richard J. Parnell[2] · Guy Anicet Rerambyath[4] · Micheline Schummer Gnandji[4] · Guy-Philippe Sounguet[7] · Manjula Tiwari[10] · Bas Verhage[11] · Raul Vilela[2] · Lee White[7] · Matthew J. Witt[8] · Angela Formia[2]

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Abstract Gabon hosts nesting grounds for several sea turtle species, including the world's largest rookery for the leatherback turtle (*Dermochelys coriacea*), Africa's largest rookery for the olive ridley turtle (*Lepidochelys olivacea*) and smaller aggregations of the hawksbill turtle (*Eretmochelys imbricata*) and green turtle (*Chelonia mydas*). To assess the level of

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✉ Paolo Casale
paolo.casale1@gmail.com

1 Department of Biology, University of Pisa, 56126 Pisa, Italy

2 Wildlife Conservation Society, Marine Program, BP 7847 Libreville, Gabon

3 Aventures Sans Frontieres, BP 7248 Libreville, Gabon

4 Direction Generale des Peches et de l'AquacultureMinistere de l'Agriculturede l'Elevagede la Peche et de la Sercurité Alimentaire, Boulevard Triomphal, BP 9498 Libreville, Gabon

5 Agence Nationale des Peches et de l'Aquaculture, Libreville, Gabon

6 Department of Biology, University of Florence, Sesto Fiorentino, 50019 Florence, Italy

7 Agence Nationale des Parcs Nationaux, BP 20379 Libreville, Gabon

8 College of Life & Environmental Sciences, University of Exeter, Cornwall Campus, Cornwall TR10 9FE, UK

9 Institut de Recherches Agronomiques et Forestieres, BP 2246 Libreville, Gabon

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incidental captures of turtles by the Gabonese trawl fishery, an onboard observer program was conducted in the period 2012–2013. A total of 143 turtles were captured by 15 trawlers during 271 fishing days. The olive ridley turtle was the main species captured (80% of bycaught turtles), with mostly adult-sized individuals. The remaining 20% included green turtles, hawksbill turtles, leatherback turtles and undetermined species. Bycatch per unit of effort (BPUE) of olive ridley turtles varied greatly depending on the period of the year (range of means: 0.261–2.270). Dead and comatose turtles were 6.2 and 24.6% respectively (n = 65). By applying the available fishing effort to two BPUE scenarios (excluding or considering a seasonal peak), the total annual number of captures was estimated as ranging between 1026 (CI 95% 746–1343) and 2581 (CI 95% 1641–3788) olive ridley turtles, with a mortality ranging from 63 (CI 95% 13–135) to 794 (CI 95% 415–1282) turtles per year depending on the scenario and on the fate of comatose turtles. Such a potential mortality may be reason for concern for the local breeding population of olive ridley turtles and recommendations in terms of possible conservation measures and further research are given.

Keywords *Lepidochelys olivacea* · Olive ridley · Gabon · Trawling fishery · Catch rate · Mortality

Introduction

The incidental catch of non-target species by fishing gear or bycatch (Kelleher 2005), has become a serious conservation challenge for marine fauna worldwide (e.g., Lewison et al. 2014; Soykan et al. 2008). Bycatch is increasingly being recognized as a major anthropogenic threat to all sea turtles species (Wallace et al. 2013) and among priority research topics for conservation (Rees et al. 2016).

Given the socio-economic importance of the fishery sector, developing acceptable mitigation measures represents one of the most complex challenges for the conservation of sea turtles worldwide (Lewison et al. 2013). The high heterogeneity of fishing gears and turtle behaviour, target species, and sea turtle species in different regions of the world represents an additional difficulty. For instance, Turtle Excluder Devices (TEDs) have been developed for trawlers, in order to divert large objects (like turtles) toward an exit in the net (Epperly 2003; FAO 2009; Rao 2011). Originally designed for small target species like shrimps, TEDs may divert larger target species like fish, decreasing their catch (e.g., Boopendranath et al. 2006; Sala et al. 2011); for this reason their implementation in fish trawling is more difficult (e.g., Behera 2006; da Silva et al. 2010).

The Atlantic coast of Africa is one of the most important regions for sea turtles globally, hosting five species (the loggerhead turtle, *Caretta caretta*; the green turtle, *Chelonia mydas*; the hawksbill turtle, *Eretmochelys imbricata*; the olive ridley turtle, *Lepidochelys olivacea*; the leatherback turtle, *Dermochelys coriacea*) (Fretey 2001; Wallace et al. 2010). However, detailed information on turtle populations and their threats in the Atlantic coast of

[10] NOAA-National Marine Fisheries Service, Southwest Fisheries Science Center, La Jolla, CA 92037, USA

[11] WWF, BP 9144 Libreville, Gabon

Africa is still limited, although increasing. One of the single most important countries for sea turtle populations in the region is Gabon, with foraging and/or nesting grounds for four species. Gabon hosts the largest population of the leatherback turtle in the world, with an estimated 36,000–126,000 nests per year and 16,000–41,000 adult females (Witt et al. 2009), and one of the largest populations of the olive ridley turtle in the Atlantic Ocean, with an estimated 2000–10,000 nests per year and 1400–8200 adult females (Metcalfe et al. 2015). Lower numbers of clutches are laid by two other species, the green and the hawksbill turtle (Gabon Sea Turtle Partnership, unpublished data). Gabonese waters also host foraging grounds for green, hawksbill, and olive ridley turtles (Formia 2002; unpubl. data).

Such aggregations may be vulnerable to incidental catch by fishing gears used in the same waters. This is particularly important for conservation, because adults are the individuals with the highest reproductive value and their mortality has the highest impact on the growth of their populations (Crouse et al. 1987; Heppell et al. 2005). Both industrial (by national and foreign vessels) and artisanal fishing occur in Gabonese waters (DGPA 2011). Artisanal fisheries are performed close to the coast or in estuaries, lagoons and protected bays such as Corisco, by small boats using a variety of fishing methods and techniques (1200–1500 units). Coastal industrial fishing consists of two métiers: (a) demersal trawlers, fishing all along the coast, but mainly in a wide area of 200 km covering the southern continental shelf in front of Loango at <50 m depth, and (b) shrimp trawlers, performing their activity exclusively in the bay of Port Gentil between 20 and 60 m depth. Finally, there is a tuna fishery, performed over the slope and further, mainly composed of purse seiners (Vilela, unpubl. data). Gabonese authorities only issue fish fishing and shrimp fishing licenses using any of the above mentioned gear configurations. Other types of licenses have been issued (i.e. longliners, gillnets or small pelagic trawlers) occasionally under specific circumstances.

The government of Gabon has made important strides toward terrestrial and marine conservation, by declaring a system of national parks in 2003 to protect approximately 80% of all sea turtle nesting activity, and establishing at least one Marine Park in the southern nesting beaches (Metcalfe et al. 2015; Witt et al. 2009) that also confers some protection to breeding turtles at sea by excluding fisheries from an area of high density habitat use (Maxwell et al. 2011; Witt et al. 2008). Extensions of the existing parks and new marine protected areas are currently under development, along with spatial planning for sustainable fishery management, spearheaded by Gabon's new Agence Nationale des Peches et de l'Aquaculture. Specifically, Gabon has already declared its intention of creating a Marine Protected Areas (MPA) network, increasing the current coverage to over 48,000 km^2 (23.8% of its exclusive economic zone, EEZ; (https://www.openchannels.org/news/mpa-news/nations-announce-new-mpa-commitments-world-parks-congress) and such a network would include both marine parks, placed in sensitive territorial waters, and marine reserves outside territorial waters, with fishing restrictions. In addition, it is planned to split the entire EEZ into fisheries management areas. Regarding sea turtles, all species are 'integrally protected' in Gabon (Decret n. 0164/PR/MEF 19/01/2011).

Sea turtle bycatch has been reported from Gabon from a variety of sources and evidence from beach strandings (Parnell et al. 2007; Riskas and Tiwari 2013). However, a specific estimation of turtle bycatch in terms of individuals, species, size class and associated mortality is lacking. To address this knowledge gap, an onboard observer program of Gabonese trawlers was launched in 2012.

Here we provide the first results regarding the sea turtle bycatch incurred by the Gabonese industrial trawl fishery, and specifically to provide information on (i) the most impacted species, (ii) life stages, (iii) bycatch levels, (iv) mortality rates, and to identify (v) priority aspects to be investigated and (vi) possible further conservation measures.

Methods

In the period 2012–2013 the Gabonese industrial trawling fleet comprised 32 active trawlers, ranging 22–42 m in length and 49.5–279 in gross tonnage (GT) operating under Gabonese flag in foreign-Gabonese joint venture companies. All shrimp trawlers had a double-rig shrimp trawling gear configuration, whilst demersal fish trawlers used either single bottom otter trawling or a double-rig gear configurations. All of them used wood and steel flat otter boards. Four of these trawlers were shrimp trawlers and as required had Turtle Excluder Devices (TEDs) installed on their nets. In order to collect information on turtle bycatch, onboard observers monitored the fishing activity of 15 trawlers, three with and 12 without TEDs, for periods ranging from 1 to 58 days for each trawler, across a 12-month period (August 2012–July 2013). These trawlers were selected opportunistically on the basis of availability of the owners and observers. The observers compiled daily reports including the number and species of turtles captured. Additional data about individual turtles were collected for a subset of the turtles (i) recorded in the daily reports, (ii) captured in other fishing days or (iii) by other trawlers. These data included turtle species, condition (conscious, comatose, dead), curved carapace length (CCL) and curved carapace width (CCW) (Bolten 1999), and scale pattern (head and carapace). At a later stage, species was confirmed or corrected through the scale pattern and through genetic analysis of skin tissue samples, if available. DNA was extracted, and the mitochondrial (mtDNA) control region was amplified and sequenced using the protocol described in Formia et al. (2006); mtDNA haplotype matching with GenBank sequences confirmed species identification. Additional data on commercial target species (relevant for understanding the potential adoption of TEDs) and haul duration were collected for a subset of hauls.

In order to ascertain whether the spatial distribution of fishing conducted by vessels supporting observers (n = 5 vessels) was similar to that of the entire VMS-tracked fleet (n = 32 vessels) we correlated the number of VMS records from both datasets (pixel resolution 2 km × 2 km) using 1000 random locations distributed throughout a zone extending from the shoreline to 50 km offshore.

In order to assess possible temporal variability of bycatch, data were organized into six two-month periods, to ensure a sample size >20 fishing days in each period. Bycatch per unit of effort (BPUE) was calculated as:

$$BPUE = \frac{\sum_{i=1}^{d} T_i}{d}$$

where d is the number of fishing days and T_i the number of turtles captured in the fishing day i. Mortality rates (MR) were calculated as:

$$MR = \frac{\sum_{i=1}^{d} M_i}{\sum_{i=1}^{d} T_i}$$

where M_i is the number of turtles considered as not surviving, captured in the fishing day i. Two extreme cases were considered, in which comatose turtles would all survive or all die (while all conscious turtles would survive), with M being respectively the number of turtles found dead or the sum of turtles found dead and those found in a comatose condition. Confidence intervals 95% (CI95%) of BPUE and MR were calculated by bootstrapping (bootstrap adjusted percentile; 10,000 replications) run in the program R (R Development Core Team 2016). Mortality per unit of effort (MPUE) was calculated as BPUE*MR and its CI95% were derived by the distribution of MPUEs obtained from the 10,000 pairs of BPUE and MR resulting from the respective bootstrapping. The number of turtles caught and the number of dead turtles per period were estimated by applying the above BPUE and MPUE to total fishing effort (fishing days) for each period.

The total fishing effort of the Gabon trawl fleet per period, which included boats with and without onboard observers, was estimated from data gathered by the Gabon vessel monitoring system (VMS), which theoretically includes all vessels, although some gaps may exist. Vessels tracked by this system report their location at a 2-h frequency to the Gabon Fisheries Surveillance Centre. Data on vessel distribution were obtained from the VMS and each 2-hourly position was assigned to one of two behaviours according to vessel speed [fishing ($0 < \text{speed} < 5$ knots) and steaming ($\text{speed} > 5$ knots)]. The number of days each boat spent fishing in the period was then estimated as the number of days with at least one fishing activity. This approach provided a minimum estimate of fishing effort as the temporal coverage of data from the VMS system was incomplete due to technical issues in operating the system. VMS data provided also the fishing areas.

Results

During the study period the Gabonese trawl fleet fished along much of Gabon's continental shelf, and in this respect the fishing locations during the monitored fishing days were not distributed differently from the total fishing effort (Fig. 1): spatial patterns of fishing vessel distribution made by the complete fleet and by vessels supporting observers significantly correlated (Spearman correlation; $n = 1000$; $\text{rho} = 0.36$; $p < 0.01$).

A total of 271 fishing days were monitored in trawlers with and without TEDs installed (34 and 237 days respectively). In a set of 611 hauls conducted by seven trawlers without TEDs in the same period, the first 20 commercial taxa (comprising 85% of the total weight) were (in order of weight from the most to the least abundant): soles (undetermined species), cassava croaker (*Pseudotolithus senegalensis*), lesser African threadfin (*Galeoides decadactylus*), sompat grunt (*Pomadasys jubelini*), cattlefish (*Sepia* spp.), Guinean barracuda (*Sphyraena afra*), catfish (*Arius* spp.), rays (undetermined species), porgies (undetermined species), largehead hairtail (*Trichiurus lepturus*), royal threadfin (*Pentanemus quinquarius*), brown ray (*Raja miraletus*), round scad (*Decapterus punctatus*), bigeye grunt (undetermined species), crabs (undetermined species), lobsters (undetermined species), pigsnout grunt (*Pomadasys rogerii*), canary drum (*Umbrina canariensis*), stingrays (undetermined species), sharks (undetermined species). In a set of 514 hauls conducted by five trawlers in the same period, the mean haul duration was 2.4 h (SD 0.6; range 0.3–6.1).

No turtles were caught by trawlers with TEDs during 34 fishing days. A total of 143 sea turtles were caught in 74 out of 237 fishing days by trawlers without TEDs: 114 (79.7%) olive ridleys (*Lepidochelys olivacea*), 12 (8.4%) green turtles (*Chelonia mydas*), three (2.1%) leatherbacks (*Dermochelys coriacea*), two (1.4%) hawksbills (*Eretmochelys imbricata*) and 12 (8.4%) turtles of undetermined species.

Specific data were collected on 84 individual turtles: 65 olive ridleys, seven green turtles, two leatherbacks, two hawksbills and eight undetermined turtles (Table 1). Further analyses were conducted on olive ridleys only. Olive ridleys had a mean CCL of 69.1 cm

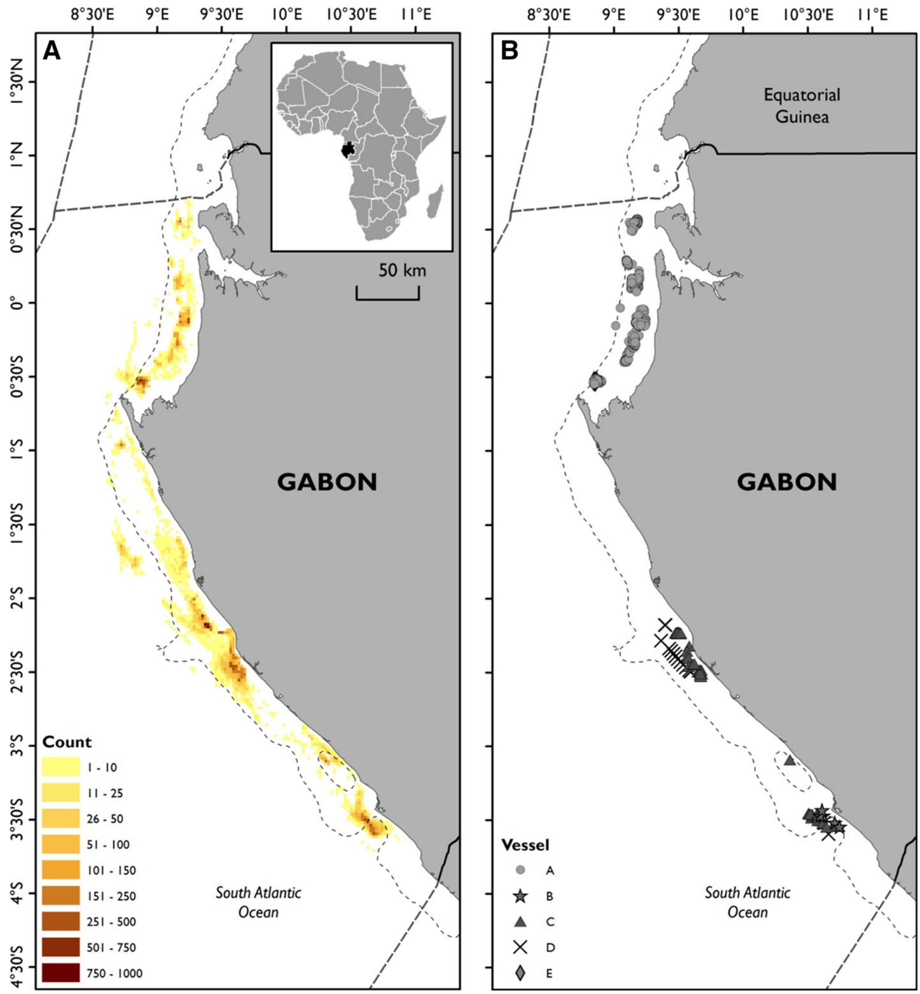

Fig. 1 Distribution of the fishing effort of the Gabonese trawl fishery in 2012–2013 (**a** 5-km^2 cells) and of a subsample of monitored vessels (**b** locations of different vessels are indicated by *symbols-letters*) obtained from vessel monitoring system (VMS) data. *Dotted line* represents the 200 m bathymetric contour

Table 1 Species, size (curved carapace length, CCL) and condition of a subsample of 84 sea turtles captured by trawlers in Gabon

Species	N	Range CCL cm (mean; SD; n)	Dead (n)	Comatose (n)	Conscious (n)
Lepidochelys olivacea	65	60.0–78.0 (69.1; 3.5; 61)	4	16	45
Chelonia mydas	7	47.5–81.0 (68.1; 14.7; 6)	0	1	6
Eretmochelys imbricata	2	60.0, 88.0	1	1	0
Dermochelys coriacea	2	147.0, 152.0	1	0	1
Undetermined	8		2	0	6
Total	84		8	18	58

(SD = 3.4 cm; range 60.0–78.0 cm; n = 61). Seventeen individuals were identified as males on the basis of the typical elongated tail, although this should be considered as a minimum number because sex was not reported for all turtles. Of the 65 olive ridley turtles sampled, 6.2% were found dead and 24.6% in a comatose state. Under the two extreme cases where comatose turtles would all survive or all die, mortality rate (MR) of olive ridley turtles was estimated at 0.0615 (CI 95% 0.0154–0.1069) and 0.3077 (CI 95% 0.1846–0.4154) respectively.

In trawlers without TEDs, the BPUE was significantly different among the six two-month periods (Kruskal–Wallis test; H = 36.5; $p < 0.001$) ranging from 0.10 turtles day^{-1} in Aug–Sep to 2.27 turtles day^{-1} in Oct–Nov (Fig. 2). Post-hoc pair-wise comparisons indicated that the period with the maximum BPUE (Oct–Nov) was significantly different from all the others ($p < 0.05$), which were not significantly different among them. Therefore, to estimate captures and mortality we considered two scenarios. In scenario A, the high BPUE of Oct–Nov was considered an anomaly and the lower BPUE (and MPUE) was applied to the entire period (12 months). In scenario B, two different BPUEs (and MPUEs) were applied to the two periods (Oct–Nov and the rest) (Table 2).

The fishing effort by the whole Gabonese trawling fleet without TEDs (n = 28), estimated from VMS data, was 3936 fishing days in the study period (Aug 2012–Jul 2013), with 774 fishing days in the period Oct–Nov 2012 and 3162 fishing days in the remaining period (Table 2). By applying these fishing efforts to the BPUEs, the total annual number of captures was estimated at 1026 (CI 95% 746–1343) and 2581 (CI 95% 1641–3788) olive ridley turtles under scenarios A and B respectively (Table 2B). The annual number of olive ridley turtles dying as a consequence of capture ranged from 63 (CI 95% 13–135) to 794 (CI 95% 415–1282) (Table 2) depending on the scenario and on the minimum or maximum MR considered (i.e. comatose turtles considered as either all surviving or all dying).

Discussion

We provide the first estimation of sea turtle bycatch level and mortality in Gabon, which hosts important nesting and foraging grounds for several sea turtle species. This estimation bears some uncertainty. First, it is based on a single year of study, and inter-annual variations may occur. Second, estimates of fishing effort in that year maybe low-biased due to possible VMS data gaps, although this is difficult to ascertain. Other uncertainties related to bycatch and mortality rates have been considered by providing different scenarios and confidence intervals.

We found that the Gabonese trawl fleet predominantly impacts a single sea turtle species (the olive ridley turtle) representing 80% of the sea turtles caught, with the remaining 20% comprising three other species. Two elements indicate that most of the olive ridley turtles captured by trawlers in the study area are adults. First, their size is similar to the average size of females nesting in Gabon (70.0 cm CCL; n = 517; Gabon Sea Turtle Partnership, unpublished data) and in a nearby nesting site (71.7 cm; n = 30; Bioko; Tomas et al. 2010). Second, the onboard observers reported several males, and males can be identified as such from the long tail, a sexual characteristic of adults that is not or less evident in immatures.

The predominance of olive ridley bycatch is somehow surprising, given that they are not the most abundant sea turtle species breeding in Gabon. Leatherback turtles are one order of magnitude more abundant than olive ridleys (Metcalfe et al. 2015; Witt et al. 2009) but

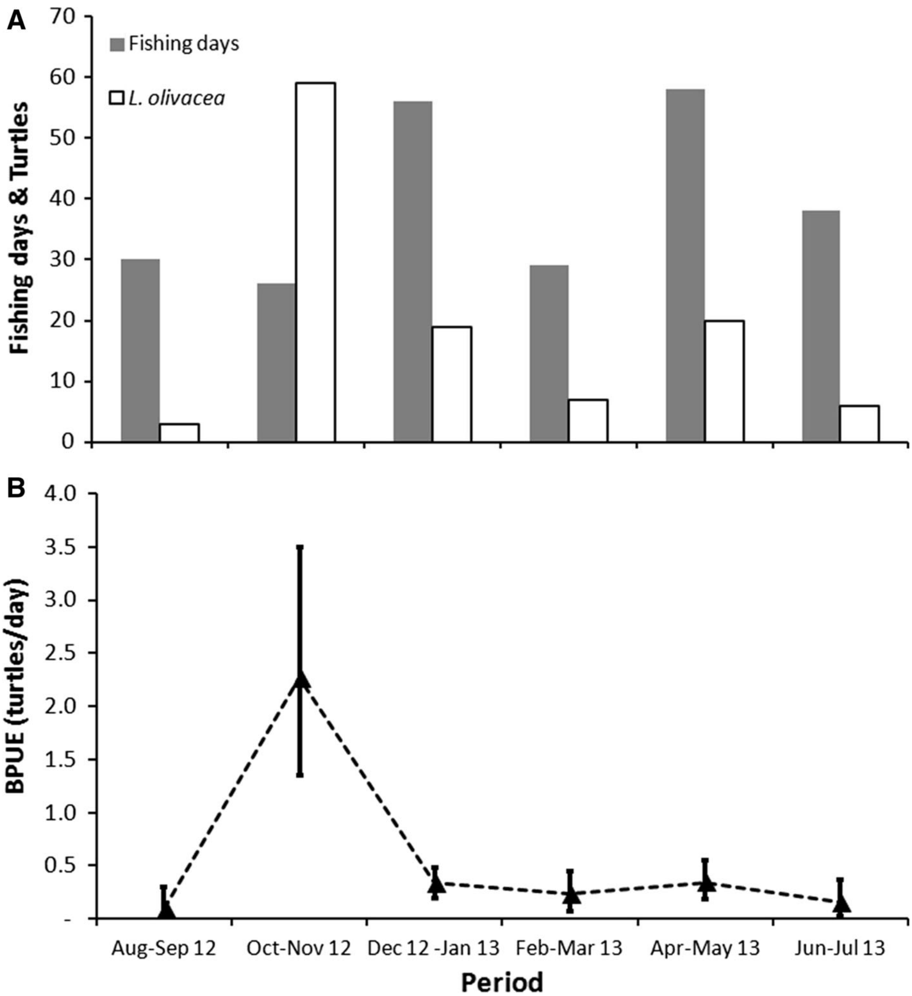

Fig. 2 **a** Number of monitored fishing days of Gabonese trawlers without Turtle Excluder Devices (TEDs) (n = 237) and number of olive ridleys turtles (*Lepidochelys olivacea*) caught (n = 114) and **b** bycatch per unit of effort (BPUE; turtles per day) of olive ridleys turtles per six 2-month periods of the year. *Vertical bars* indicate CI 95% of BPUE

represent only 2% of the sea turtles captured. Olive ridleys are the most abundant species also among dead turtles stranded along the southern coast of Gabon, where these strandings were thought to be caused by fishery interaction (Parnell et al. 2007). Tentative explanations of this incongruence between nesting and bycatch levels of the two species are: (i) a lower occurrence of leatherbacks in the trawling area, (ii) a lower occurrence of leatherbacks in the lower part of the water column (where the trawl net is towed), or (iii) a higher avoidance capability of leatherbacks. The first explanation is not supported by a comparison of the internesting areas of leatherback and olive ridley adult females in the southern part of Gabon, obtained through satellite tracking, with both species mostly frequenting the same waters shallower than 100 m (Maxwell et al. 2011; Witt et al. 2008). The second explanation is supported by satellite tracking data in Gabon, showing that

Table 2 Estimate of the number of olive ridleys turtles (*Lepidochelys olivacea*) captured and killed by the Gabonese trawling fleet under different scenarios of bycatch per unit of effort (BPUE) and mortality per unit of effort (MPUE) (turtles per day), depending on the period of the year and on the fate of comatose turtles (see text for details)

	Mean (CI 95%)			
	Scenario A	Scenario B		
	Entire period (low BPUE)	Oct-Nov	Other months	Total
BPUE	0.261 (0.190–0.341)	2.270 (1.350–3.500)	0.261 (0.190–0.341)	
MPUE min	0.016 (0.003–0.034)	0.138 (0.024–0.312)	0.0161 (0.003–0.034)	
MPUE max	0.080 (0.046–0.122)	0.700 (0.350–1.157)	0.080 (0.046–0.122)	
Fishing effort (days)	3936	774	3162	3936
Estimated turtle captured	1026 (746–1343)	1756 (1042–2709)	824 (600–1079)	2581 (1641–3788)
Estimated mortality				
Turtles min	63 (13–135)	107 (19–242)	51 (11–108)	158 (30–350)
Turtles max	315 (183–481)	540 (268–895)	253 (147–386)	794 (415–1282)

during their internesting period leatherback turtles spent most time in the middle of the water column with few or no contacts with the sea bottom (M. Witt, unpublished data), while olive ridleys spend much of their time in the lower water column or on the seafloor (S. Maxwell, unpublished data), as is also observed in Oman and Australia (Hamel et al. 2008; Rees et al. 2012). The third explanation regarding the potential for differential avoidance behavior between species is plausible, however no direct observations are available.

Although based on different units of effort, the present BPUEs (0.26–2.27 turtles day^{-1}) seem to be lower than BPUEs reported from Costa Rica (0.10 turtles h^{-1}; Arauz et al. 1998) or India (0.07–0.48 turtles h^{-1}; Gopi et al. 2007), which host larger nesting populations of olive ridley turtles. Present results suggest a strong seasonality of bycatch, although a larger dataset considering sub-areas and multiple years is needed to confirm such a seasonal bycatch variation and to explore a variety of potential factors. The observed peak in BPUE (October–November) coincides with the peak in nesting (Metcalfe et al. 2015). This likely suggests that bycatch seasonality could largely be due to breeding seasonality and further supports the proposed “Scenario B” and that adults are the main category incidentally captured by trawlers, as is also indicated by turtle size. Congruously, satellite tracking data showed that females breeding in Gabon stay in relatively shallow waters close to the nesting sites during the internesting period (Maxwell et al. 2011), then most of them migrate to more offshore foraging grounds, distant from the area monitored by this study (Pikesley et al. 2013).

The observed mortality rate (6.2%) was lower than mortality rates reported for the same species from Costa Rica (37.5%; Arauz et al. 1998) or Australia (12.5%; Poiner and Harris 1996). Haul duration is known to have a significant effect on turtle mortality (Sasso and

Epperly 2006). However, the average haul duration observed in Gabon was relatively high (2.4 h) and was not much lower than Australia (2.6–3.1 h; Poiner and Harris 1996). Further investigation on this and other potential mortality factors is needed to inform mitigation approaches. For instance, decompression sickness (García-Párraga et al. 2014) may represent an elusive mortality factor that can increase current estimates.

Assuming that the study year was representative of the turtle bycatch, the estimated level of bycatch and associated mortality could have a negative impact on the Gabonese olive ridley population. With an adult population estimated at 1400–8200 females (Metcalfe et al. 2015) and even considering a comparable number of males, the 400–1300 adults estimated to be killed per year in the worst case scenario (highest catch rate and highest mortality) would represent a significant loss for the population. Both population abundance and bycatch estimates bear a high uncertainty and further work is needed to understand the real impact. For instance, even a relatively simple approach such as the Potential Biological Removal (PBR) (e.g., Casale and Heppell 2016) requires an estimations of population abundance that can only be obtained through a better knowledge of population dynamics than currently available for the Gabonese olive ridley turtle population. However, under a precautionary approach, these preliminary findings highlight the need to explore ways to reduce the impact of bycatch in this fishery.

A variety of mitigation measures can be suitable for the local context and should be pursued altogether as a synergic strategy. First, turtle bycatch can be reduced by installing TEDs on a larger part of the fleet. So far TEDs have been installed on shrimp trawlers only, because TED selects on the basis of target size and was originally designed for shrimp trawling (Epperly 2003), therefore it may cause a reduction of the catch of larger commercial species, like the ones observed in this study. In order to install TEDs on fish trawlers, testing and adjusting TED design is needed, as done in other areas (e.g., Boopendranath et al. 2006; Sala et al. 2011), and is currently underway in Gabon and is expected to lead to the establishment of TEDs throughout the trawler fleet. Second, turtle bycatch can be reduced by reducing the total fishing effort or by displacing it to areas/periods with a lower turtle occurrence. The latter approach requires the identification of turtle hot-spot areas/periods and setting up of managed areas (e.g. Marine Protected Areas, MPA) which would be included in the MPA network the government of Gabon is already planning (see "Introduction"). If confirmed, the bycatch seasonal peak reported by this study would provide an excellent opportunity to significantly reduce turtle bycatch through a limited time restriction in fishing. Third, the impact of trawling on turtles can be reduced by reducing the mortality rate of captured individuals. Present results indicate that the direct mortality rate (i.e. turtles found already dead) is relatively low and much lower than the potential post-release mortality of comatose turtles. This post-release mortality component can be significantly decreased if turtles are allowed to recover on board before being released (FAO 2009). This is a simple best-practice that the observer program should continue to expand and strengthen in the fleet and which would significantly reduce the total mortality and the overall impact of trawling on the olive ridley turtle population. Reducing tow duration is another possible approach to reduce both the direct mortality rate and the comatose rate, because tow duration is the main parameter associated with mortality caused by forced apnoea, since long tow duration may cause long forced apnoea, depending on when the turtle has entered the net (Sasso and Epperly 2006). However, tow duration is based on fishing optimization, therefore its limitation may encounter resistance and would be difficult to enforce.

Fishing in Gabon is not limited to national trawlers. First, vessels from other countries (i.e., EU, Japan, Korea, etc.) are allowed to fish in the zone from 6 to 200 miles offshore

(Le Code des Peches et de l'Aquaculture, Law 15/2005, 8 August 2005) and may cause further mortality, depending on the fishing gear they use. Second, like in other West African countries (Riskas and Tiwari 2013), different fishing gears are used, especially artisanal gears like nets, which are known to cause a very high mortality rate in other areas (e.g. Benin: 86%; Dossa et al. 2007). Such fishing gears are more difficult to study and even to census, because they are deployed by very small boats or even from land, and are typically widespread. A survey conducted in 2008 registered between 1400 and 1500 artisanal fishing vessels and another survey in 2014 estimated 949 vessels in north Gabon alone (Cardiec 2014). Present results indicate a high occurrence of turtles in the shallow coastal zone and high fishing effort by the artisanal fishery may result in high turtle bycatch levels and associated mortality.

In conclusion, present findings highlight a potential impact of the Gabonese industrial trawl fishery to West Africa's olive ridley population, and thus to overall population size in the Atlantic, through high bycatch and overall mortality levels of the adult component of the population. Adults may also be subject to incidental catch by foreign trawlers and other fishing gears, including artisanal gears, acting in the same fishing area. We recommend: (i) to develop and implement TEDs suitable for fish trawlers, (ii) continue and possibly extend the information/education campaign targeting fishermen, with a specific focus on onboard best-practices to reduce post-release mortality of captured turtles; (iii) expand the present study in terms of fleet coverage, number of fishing days, number of years, and type of data, in order to reduce the confidence intervals of catch and mortality rates, to assess seasonal and interannual variability, and to identify hot-spot bycatch areas; (iv) improve the estimate of total fishing effort by trawlers in Gabon, in order to improve bycatch estimations; (v) carry out additional fishery-independent studies (e.g., satellite tracking, aerial surveys) on the distribution of different turtle species in Gabonese waters in order to identify hot-spot areas for sea turtles; (vi) estimate sea turtle bycatch in other fishing gears, especially the artisanal fishery, in order to assess their importance as a threat.

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