



New biological observations on the sandbar shark *Carcharhinus plumbeus* (Chondrichthyes: Carcharhinidae) from the coast of Senegal (Eastern Tropical Atlantic)

Youssouph DIATTA¹, Amadou Abdoulaye SECK^{1*}, Christian REYNAUD²
Olivier GUELORGET² and Christian CAPAPÉ²

⁽¹⁾ Laboratoire de Biologie Marine, Institut Fondamental d'Afrique noire Cheikh Anta Diop, BP 206, Dakar, Sénégal.

**tragically died on duty on 5 July 2007 in Casamance (southern Senegal).*

⁽²⁾ Laboratoire d'Ichtyologie, case 104, Université Montpellier II, Sciences et Techniques du Languedoc,
34 095 Montpellier cedex 5, France. E-mail: capape@univ-montp2.fr

Abstract: The sandbar shark, *Carcharhinus plumbeus*, is landed in fishing sites located along the coast of Senegal (Eastern tropical Atlantic). The smallest mature male was 165 cm in total length (TL) and weighed 14 kg while the largest male reached 193.5 cm TL and weighed 32 kg. The smallest adult female was 179 cm TL and weighed 25 kg while the largest female was 225 cm TL and weighed 64 kg. Parturition occurred from April to June. The gestation period was estimated at twelve months, at most. Females appeared to reproduce every two years. Size and mass at birth were based on near-term embryos and neonates; it probably occurred between 58 and 65 cm TL (mean: 60.3 cm \pm 1.55) and between 0.92 and 1.52 kg (mean: 1.08 kg \pm 0.133). Litter sizes ranged from 4 to 12. Embryos and post-partum males did not significantly outnumber the females.

Résumé : *Nouvelles observations biologiques sur le requin gris Carcharhinus plumbeus (Chondrichthyes : Carcharhinidae) de la côte du Sénégal (Atlantique orientale tropicale).* Le requin gris, *Carcharhinus plumbeus*, est débarqué dans les sites de pêche se trouvant le long de la côte du Sénégal (Atlantique orientale tropicale). Le plus petit adulte mâle mesurait 165 cm de longueur totale (LT) et pesait 14 kg, tandis que le plus grand mâle atteignait 193,5 cm LT et pesait 32 kg. La plus petite femelle adulte mesurait 179 cm LT et pesait 25 kg alors que la plus grande femelle mesurait 225 cm et pesait 64 kg. La parturition a lieu d'avril à juin. La période de gestation est estimée à douze mois, au plus. Les femelles semblent se reproduire tous les deux ans. La taille et la masse à la naissance sont fondées sur des embryons à terme et des néonates ; elles se situent probablement entre 58 et 65 cm LT (moyenne : 60 cm \pm 1,6) et 0,92 et 1,52 kg (moyenne : 1,08 kg \pm 0,133). Les portées comprennent entre 4 et 12 individus. Les embryons et les mâles post-partum ne sont pas significativement plus nombreux que les femelles.

Keywords : Chondrichthyes • Carcharhinidae • *Carcharhinus plumbeus* • Reproduction • Senegal • Eastern Tropical Atlantic

Introduction

Carcharhinus plumbeus (Nardo, 1827) is a migratory medium-size shark that is widely distributed in warm temperate to tropical waters (Compagno, 1984). The species is known to occur on both sides of the Atlantic and in the Pacific and Indian Oceans where it is targeted (McAuley et al., 2007). *C. plumbeus* is found in the Mediterranean, especially in the Gulf of Gabès, where it lives and reproduces and where nursery areas have been described (Bradaï et al., 2005; Saïdi et al., 2005). Off the coast of Senegal, *C. plumbeus* is the focus of an intensive fishery, both commercial and artisanal, for human consumption. The flesh is dried under the vernacular name of 'sali', it is used locally or exported to other African countries. However, similar to previous observations in the area (Cadenat & Blache, 1981), sandbar sharks were less frequently landed during this study than other local shark species. Locally, the sandbar shark has probably faced a population decline such as in other marine regions (McAuley et al., 2007). This needs a great urge for the establishment of shark monitoring off the Senegalese coast, including *C. plumbeus*. Consequently, reproduction parameters need to be assessed for stock management purposes, such as size at birth, size at sexual maturity, reproductive cycle, embryonic development, embryonic sex-ratio and fecundity. The new data presented in this article complete previous information obtained from *C. plumbeus* caught off Senegal (Cadenat & Blache, 1981; Capapé et al., 1994); they are compared and contrasted with those reported off other marine areas, especially off Tunisia (Bradaï et al., 2005; Saïdi et al., 2005, 2006 & 2007).

Material and Methods

A total of 136 sandbar sharks, 74 males and 62 females, were collected off the Senegalese coast between 1995 and 2005. The specimens were caught by demersal gill-nets, generally on sandy bottoms at depths of 20-100 m, but occasionally on muddy and detritic bottoms (Fig. 1). In addition, 85 embryos were examined. The specimens were measured for total length (TL) to the nearest cm following Bass et al. (1973) and weighed to the nearest 10 g. Clasper length (CL, mm) was measured according Collenot (1969), from the anterior rim of the pelvic girdle to the tip of claspers. Oocytes were removed from the ovaries, measured and weighed.

Size at sexual maturity in males was determined from the length and condition of claspers following Collenot (1969), Bass et al. (1973) and Watson & Smale (1998). Aspects of the testes and other reproductive organs were also considered in this study, following Capapé et al. (1990)

and Henderson et al. (2006). In juvenile males, claspers were shorter than the pelvic fin, flexible and not calcified, while genital ducts were slightly developed and thread-like. In sub-adults, claspers were longer than the pelvic fin, flexible, and slightly calcified, both testes were slightly developed, but no spermatocysts were externally visible and no sperm occurred in the seminal vesicles. The genital ducts were visible and the *ductus deferens* (Hamlett et al., 1999; Callard et al., 2005) was slightly convoluted. In adults, claspers were longer than the pelvic fins, rigid and calcified while spermatocysts were externally visible and seminal vesicles contained sperm. The *ductus deferens* was twisted. Size at sexual maturity in females was determined from the condition of the ovaries and the morphology of the reproductive tract following Hamlett et al. (1999). Juvenile females exhibited thread-like ovaries and oviducts, and

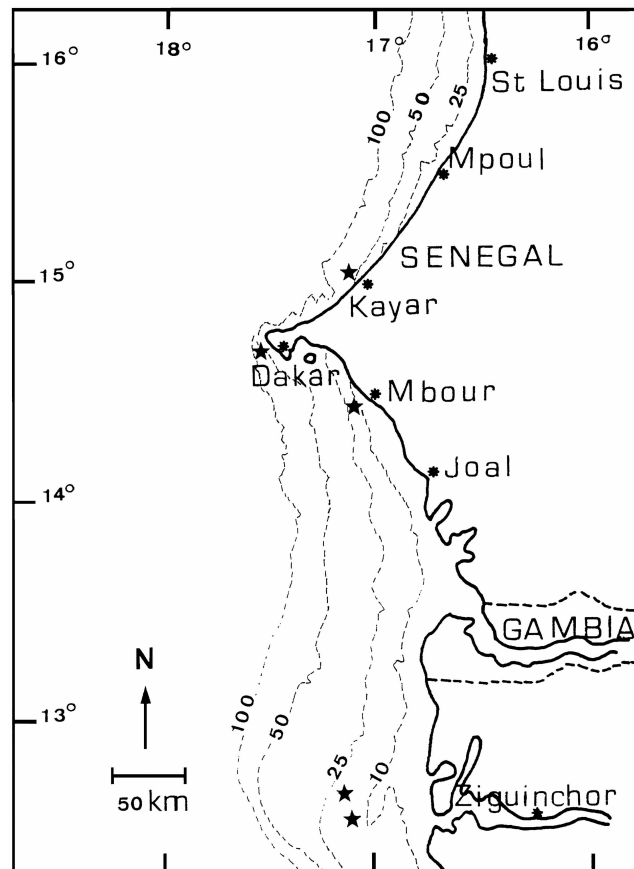


Figure 1. *Carcharhinus plumbeus*. Map of Senegal showing the landing sites and captures sites (black stars), redrawn from Capapé et al. (2006a). Depth contour in metres.

Figure 1. *Carcharhinus plumbeus*. Carte du Sénégal montrant les sites de débarquement et les sites de captures (étoiles noires), redessiné d'après Capapé et al. (2006a). Contours des profondeurs en mètres.

inconspicuous oviducal glands. Sub-adults had ovaries with translucent oocytes, well-differentiated genital ducts, and visible oviducal glands. Different categories of adult females were considered following McAuley et al. (2007). Adults had genital tract completely developed with ovary clearly distinguishable from epigonal organ and with differentiated oocytes. Pregnant females contained visible embryos at different stages of development. In post-partum females, the uteri were enlarged and flaccid, with conspicuous placental attachment sites.

ANOVA and chi square test were used for significance ($p < 0.05$). In the relationship mass to total length, linear regression was expressed in decimal logarithmic metrics, correlations were assessed by least-squares regression and ANCOVA was used to compare curves for different sexes.

Results

Sample description

The sample comprised 136 sandbar sharks, males, 74 specimens, did not significantly outnumber the females, 62 specimens ($\chi^2 = 3.1$; $df = 1$). The monthly collection of the observed specimens is presented in Table 1. Across all the three categories of free-swimming specimens, males and females were not equally distributed in our sample. However, in each category the males did not significantly outnumber the females, χ^2 were 2.5, 1.3 and 1.4 between juveniles, sub-adults and adults, respectively, with $df = 1$. The sample included 15 neonates, 10 males and 5 females; additionally, 31 near-term embryos, 16 males and 15 females (Table 2, records 8 to 11), were examined.

Size of males

In all, 52 juvenile males were observed, ranging in total length between 58 and 132 cm and weighing between 1.02 and 12.40 kg. Eleven specimens (58-65 cm TL, 1.020-1.520 kg) had an unhealed umbilical scar on the ventral surface and were probably neonates. Juveniles were mostly caught in May, June and September.

Twelve sub-adults were observed, ranging 138-165 cm TL and 14.00-21.00 kg. The heaviest was 21.00 kg. The claspers were flexible and slightly calcified. They grew fastest during this stage (Fig. 2). Some sub-adults were caught between January and May (Table 1).

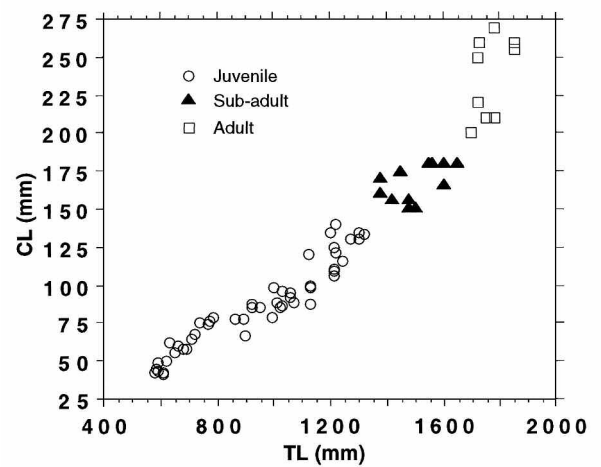


Figure 2. *Carcharhinus plumbeus*. Relationship between Clasper Length (CL) and Total Length (TL) in males.

Figure 2. *Carcharhinus plumbeus*. Relation entre la longueur des ptérygopodes (CL) et la longueur totale (TL) chez les mâles.

Table 1. *Carcharhinus plumbeus*. Monthly collection of observed specimens in the sample.

Tableau 1. *Carcharhinus plumbeus*. Récolte mensuelle des spécimens observés dans l'échantillon.

Sex	Category	Months												Total
		Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	
Males														
	Juveniles	6	1	1	4	7	16	2	4	8	1	-	2	52
	Sub-adults	1	2	1	2	2	2	-	1	-	1	-	-	12
	Adults	-	-	-	3	6	1	-	-	-	-	-	-	10
	Total	7	3	2	9	15	19	2	5	8	2	-	2	74
Females														
	Juveniles	3	3	2	1	6	7	4	5	5	-	2	1	39
	Sub-adults	2	3	-	-	1	-	-	-	-	-	1	-	7
	Adults	-	3	2	3	4	2	-	-	-	-	1	1	16
	Total	5	9	4	4	11	9	4	5	5	-	4	2	62
Grand total		12	12	6	13	26	28	6	10	13	2	4	4	136

Table 2. *Carcharhinus plumbeus*. Reproductive cycle of females. Condition of ovary and uteri during gestation.

Tableau 2. *Carcharhinus plumbeus*. Cycle de reproduction des femelles. Etat de l'ovaire et des utérus pendant la gestation.

Record Number	Month of catch	Size of female (TL, mm)	Mass of female (g)	Ovarian activity	Oocyte diameter (mm)	Oocyte number	Uterine content	Embryo size (TL, mm)	Embryo mass (g)	Embryo number (left+right)	Embryo male-female (m+f)
1	Feb	1870	27500	Resting	-	-	Embryos	325-350	300-345	3+3	2 m+4 f
2	Feb	1870	28500	Resting	-	-	Embryos	410-440	540-615	4+3	4 m+3f
3	Feb	1900	?	Resting	-	-	Embryos	?	?	?	?
4	Mar	2150	?	Resting	-	-	Embryos	420-480	580-780	6+6	6m+6f
5	Mar	2200	64000	Resting	-	-	Embryos	400-450	410-580	5+5	5m+5f
6	Apr	1870	33000	Resting	-	-	Embryos	535-605	750-855	4+2	4m+2f
7	Apr	1850	28000	Resting	-	-	Embryos	430-510	540-690	3+4	3m+4f
8	Apr	1860	32000	Vitellogenesis	6	numerous	Embryos	590-612	960-1050	4+4	4m+4f
9	May	1800	31500	Vitellogenesis	4-6	numerous	Embryos	590-610	1000-1130	2+2	2m+2f
10	May	2050	55000	Vitellogenesis	4-6	numerous	Embryos	585-620	920-1100	5+5	5m+5f
11	May	2200	59000	Vitellogenesis	4.5	numerous	Embryos	590-620	960-1100	5+4	4m+5f
12	May	2000	59000	Vitellogenesis	8-10	numerous	-	-	-	-	-
13	June	2100	54000	Vitellogenesis	6-8	numerous	-	-	-	-	-
14	June	1790	25000	Vitellogenesis	8-10	numerous	-	-	-	-	-
15	Nov	1900	38000	Resting	-	numerous	Embryos	< 100	?	3+3	3m+3f
16	Dec	1880	?	Resting	-	numerous	Embryos	< 100	?	?	?

Ten adults were examined, their size ranged between 165 and 185 cm TL, and they weighed from 19.50 to 32.00 kg. The claspers were rigid, calcified, elongated, and longer than the pelvic fins. Adults were landed in March, April and May (Table 1).

Size of females

Juvenile females ranged 58-147 cm TL and 0.58-16.00 kg. Of the 39 juveniles examined, 5 were neonates with unhealed scars on the ventral surface, ranging from 58-65 cm and weighing up to 0.98 kg.

The 7 sub-adult females ranged 148-163 cm TL and 15.40-16.80 kg. Specimens were generally caught in January and February (Table 1).

Sixteen adult females were examined. They ranged between 179 and 225 cm TL and weighed between 25.00 and 64.00 kg. Nine were pregnant and carrying term embryos. They were caught in April and June (Table 1).

Size-mass relationship

The relationship between total length (TL) and total mass (TM) was not significantly different between males and females ($F = 0.41$, $p = 0.50$). The relationships were, for males:

$$\log TM = 2.84 \log TL - 4.80, r = 0.98, n = 74 \quad (1)$$

for females:

$$\log TM = 2.89 \log TL - 4.93, r = 0.99, n = 62 \quad (2)$$

and for both sexes combined (Fig. 3):

$$\log TM = 2.87 \log TL - 4.88, r = 0.98, n = 136 \quad (3)$$

Reproductive status of females

A single ovary and both uteri are functional in adult *C. plumbeus* females. Of the 16 examined specimens, 13 were pregnant and bore embryos and only three females were non-pregnant (Table 2). Among the pregnant females, nine females bore developing embryos and the ovary was in a resting phase. Developing embryos observed less than 10 cm TL were free in uteri, unpigmented and exhibited a large, developed and vascularized yolk sac and external gill filaments. Embryos between 32.5-35 cm TL were completely formed and pigmented, and were connected by a smooth and unadorned umbilical stalk to the placenta that was established and attached to the internal uterine wall. The umbilical stalk was between 16.5 and 20 cm length, umbilical stalk+placenta weighed between 2.8 and 3.8 g, slight remains of yolk were still present in the placenta. Both uteri were compartmented in chambers, and in each chamber a single embryo developed. Similar patterns were observed in larger developing

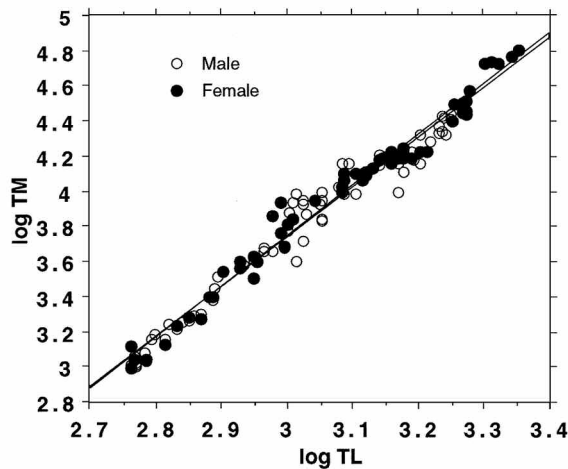


Figure 3. *Carcharhinus plumbeus*. Relationship between Total Mass (TM) and Total Length (TL) expressed in logarithmic metrics for males and for females.

Figure 3. *Carcharhinus plumbeus*. Relation entre la masse totale (TM) et la longueur totale (TL) exprimée en métrique logarithmique pour les mâles et les femelles.

embryos, additionally the length of umbilical stalk increased (28-35 cm), whereas umbilical stalk+placenta mass slightly decreased. Based on the size of the smallest observed free-swimming neonates, four pregnant females bore near-term embryos and the ovary exhibited oocytes slightly charged by yolk, they were numerous and the diameter was between 4 and 6 mm. In all, 31 near-term embryos, 16 males and 15 females, were examined. The size ranged between 58.5 and 62 cm TL and weighing

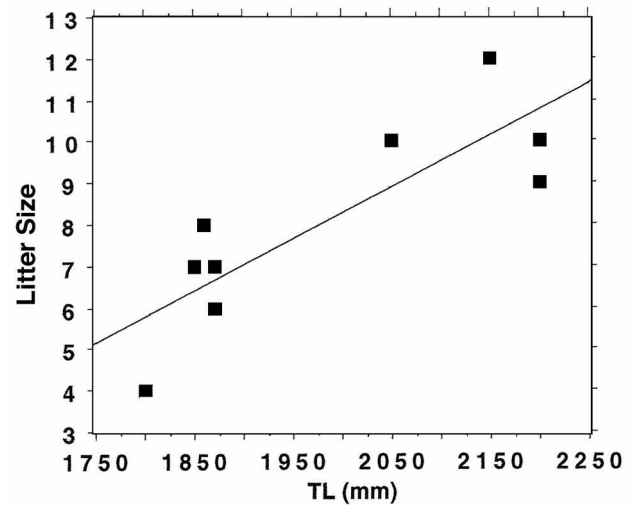


Figure 4. *Carcharhinus plumbeus*. Relationship between litter size and Total Length (TL).

Figure 4. *Carcharhinus plumbeus*. Relation entre le nombre d'individus par portée et la longueur totale (TL).

between 0.92 and 1.13 kg. The length of the umbilical stalk was between 39 and 43 cm TL and umbilical stalk+placenta weighed between 3.1-3.5 g. Three non-pregnant females had ovaries containing yolky oocytes with diameter between 8-10 mm while uteri showed placental attachment sites; they probably were recent postpartum specimens.

Litter size

Litter size ranged from 4 to 12 with a mean of 7.7. Litter size was related to total length of females (Fig. 4):

$$\text{Litter size} = 0.01 \text{ TL} - 16.73, r = 0.84. \quad (4)$$

Table 3. *Carcharhinus plumbeus*. Sizes at sexual maturity and maximal sizes reported from different marine areas.

Tableau 3. *Carcharhinus plumbeus*. Tailles à la maturité sexuelle et tailles maximales relevées en différentes régions marines.

Size at sexual maturity (TL, mm)		Maximal size (TL, mm)		Area	Authors
Males	Females	Males	Females		
1560	1580	-	-	Northern Australia	Stevens & McLoughlin (1991)
1630	1900	2260	2470	South Africa	Bass et al. (1973)
1800	1770	2130	2200	Mauritius	Wheeler (1962)
1760		1760		Red Sea	Baranes & Ben-Tuvia (1978)
1800		2500		Western Atlantic	Bigelow & Schroeder (1948)
1830	1830	2260	2300	Western Atlantic	Springer (1960)
1920	1850	2040	2340	Western Atlantic	Clark & Von Schmidt (1965)
1840	1890	1900	2030	Gulf of Mexico	Branstetter (1981)
1800	1850	2230	2290	Eastern tropical Atlantic	Cadenat & Blache (1981)
1900		1900		Italian Seas	Bini (1967)
1660	1700	2250	2480	Coast of Tunisia	Capapé (1984)
1545-1600	1660-1720	1935	2185	Gulf of Gabès	Saïdi et al. (2005)
1650	1850	1790	2250	Coast of Senegal	This study

Table 4. *Carcharhinus plumbeus*. Size at birth of reported from different marine areas.

Tableau 4. *Carcharhinus plumbeus*. Tailles à la naissance relevées en différentes régions.

Size at birth (mm)	Area	Authors
530-660	Northern Australia	Stevens & Mc Loughlin (1991)
600-750	China Sea	Taniuchi (1971)
600-750	South Africa	Bass et al. (1973)
400-500	South Africa	Cliff et al. (1988)
≈ 510	Western Atlantic	Springer (1960)
≈ 597	Western tropical Atlantic	Amorim et al. (1998)
546-605	Eastern tropical Atlantic	Cadenat & Blache (1981)
> 440	Italian Seas	Tortonese (1956)
580-650	Coast of Tunisia	Capapé (1984)
450-650	Gulf of Gabès	Saïdi et al. (2005)
580-650	Coast of Senegal	This study

Table 5. *Carcharhinus plumbeus*. Litter size reported from different marine areas.

Tableau 5. *Carcharhinus plumbeus*. Nombres d'individus par portée relevés en différentes régions.

Litter size	Area	Authors
3-8	Northern Australia	Stevens & Mc Loughlin (1991)
2-10	China Sea	Taniuchi (1971)
1-8	Hawaiï	Tester (1969)
8	South Africa	Bass et al. (1973)
4-10	South Africa	Cliff et al. (1988)
6	Red Sea	Baranes & Ben-Tuvia (1978)
1-14	Western Atlantic	Springer (1960)
4-11	Western Atlantic	Clark & Von Schmidt (1965)
7-10	Western tropical Atlantic	Amorim et al. (1998)
5-12	Eastern tropical Atlantic	Cadenat & Blache (1981)
18	Italian Seas	Lo Bianco (1909)
3-14	Coast of Tunisia	Capapé (1984)
4-10	Gulf of Gabès	Saïdi et al. (2005)
4-12	Coast of Senegal	This study

Of the 85 sexed embryos, 41 were males and 44 were females, the latter did not significantly outnumber the former ($\chi^2 = 0.2$, $df = 1$).

Discussion

Landings of sandbar sharks occurred year round and contained juveniles and sub-adults, although captures of adults were relatively less abundant. Among the females,

we found both pregnant and post-partum specimens, which may have been present in shallow coastal waters in order to find favourable environmental conditions for neonates. Bradai et al. (2005) and Saïdi et al. (2005) noted a similar phenomenon for Tunisian *C. plumbeus*, and Capapé et al. (2006a & b) for other sympatric shark species off the coast of Senegal.

The sampled males *C. plumbeus* were sexually mature at a lower size than females and reached a lower maximum size. Sexual dimorphism in size was also observed in sandbar sharks from other areas (Table 3). These observations are in agreement with Leloup & Oliveureau (1951). The general pattern of latitudinal variation in maturity and maximum size was reported in several other chondrichthyan species (Mellinger, 1989). Similar patterns were observed in other carcharinid species (Capapé et al., 2003, 2006b) and in the bonnethead sharks *Sphyrna tiburo* (Linnaeus, 1758), from the eastern Gulf of Mexico by Lombardi-Carlson et al. (2003) who noted that latitudinal differences are thought to be the results of environmental factors, but may be also due to physiological constraints or genetic factors. The observed *C. plumbeus* were slightly smaller than those observed three decades ago by Cadenat & Blache (1981) in the area. These differences may be due to sampling; however, the possibility of this observation being a consequence of high fishing pressure cannot be excluded. Similar patterns were reported for sandbar sharks from off the western Australian waters (McAuley et al., 2007). Our observations showed that size at birth probably occurred between 58 and 65 cm TL (mean: 60.3 cm \pm 1.6) and mass at birth between 0.92 and 1.52 kg (mean: 1.077 kg \pm 0.133). Size at birth also varies with location (Table 4), however intra-specific changes may be due to sampling. Off South Africa, specimens observed by Cliff et al. (1988) are smaller than those observed 25 years ago by Bass et al. (1973). In contrast, free-swimming specimens sampled in this study were larger than those observed by Cadenat & Blache (1981).

Pregnant females carrying near-term embryos were caught in April-May, while post-partum females in May-June (Table 2), this suggests that gestation lasted 11 months, 12 months at most, in agreement with previous findings of Bass et al. (1973) and Cliff et al. (1988) off South African coast, Taniuchi (1971) for Sea China, Wass (1973) off Hawaiï, Saïdi et al. (2005) in the Gulf of Gabès and McAuley et al. (2007) in western Australian waters. During gestation, the ovary was in a resting phase. Additionally, vitellogenesis started at the end of the

gestation, then the embryos were probably close to being expelled by mothers (Table 2), and oocytes had started to be charged by yolk. Consequently, vitellogenesis did not proceed in parallel with gestation; instead it suggested that oocytes developed when uteri were in a resting phase. These data suggest *C. plumbeus* reproduced in alternate year off the coast of Senegal, as it is practically the rule for the species (Springer, 1960; Wass, 1973; Cliff et al., 1988; Saïdi et al., 2005; McAuley et al., 2007). Capapé et al. (2003) noted that the gestation period could be subdivided into three phases in the spinner shark, *Carcharhinus brevipinna* (Müller & Henle, 1841). During the first period, two months, the embryos were nourished by the yolk, during the second period the embryos were concomitantly nourished by the yolk and nutriment provided by the mother, they were lecitho-matrotrophic, and then during the third period, nutriment was exclusively supplied by the mother, embryos were strictly matrotrophic. Similar patterns were observed in Senegalese *C. plumbeus*. The first period was clearly observed (Table 2), as the third period (Table 2). However, in record 1, the remains of yolk observed in embryos' placentae suggests that they were at the end of the second phase of the gestation period. Consequently, *C. plumbeus* could be considered as a strict matrotrophic species (*sensu* Hamlett et al., 2005).

Litter sizes were positively correlated with the size of females and ranged from 4-12, they were not different from those reported for other sandbar sharks elsewhere (Table 4) and similar to those of sympatric Senegalese populations of *Rhizoprionodon acutus* (Rüppell, 1835) and *Mustelus mustelus* (Linnaeus, 1758) which ranged from 1-8 and 4-21 respectively (Capapé et al., 2006a & b). Additionally, *R. acutus* and *M. mustelus* reproduce annually in the Senegalese waters (Capapé et al., 2006a & b), whereas *C. plumbeus* reproduces every two years. Embryos were observed in practically equal numbers in each uterus of in *C. plumbeus* (see Table 2). Stevens & McLoughlin (1991) noted that the sex ratio was 1:1 in all areas for which information is available (Springer, 1960; Taniuchi, 1971; Bass et al., 1973; Wass, 1973; Baranes & Wendling, 1981). Additionally, Amorim et al. (1998) found 35 females and 25 males in 15 pregnant females. Generally, female and male embryos occurred in equal numbers in carcharhinid species (Stevens & McLoughlin, 1991; Capapé et al., 2003). In our post partum sample, in all categories of specimens, males outnumbered females, this phenomenon may be due to segregation with size and sex in elasmobranch species (see Muñoz-Chapuli, 1984), mainly in *C. plumbeus* in western Australian waters (McAuley, 2007). In contrast, Bradai et al. (2005) noted that neonate *C. plumbeus* females significantly outnumbered males among sampled specimens from the Gulf of Gabès. Although, an important competition pressure predation by larger sharks, *C.*

plumbeus was the dominant shark in the area, where prey availability allowed to support *C. plumbeus* nurseries (Bradai et al., 2005; Saïdi et al., 2005, 2006 & 2007). Although the Senegalese waters present a large prey availability (Diatta et al., 2001), *C. plumbeus* is apparently less frequently landed in Senegalese fishery sites than its sympatric elasmobranch species, probably as a result of an intensive inter-specific competition, larger sharks are present in the area (Capapé et al., 1994 & 1998), but the relative scarcity of sandbar sharks off Senegal may be also due to its *K*-selected biological characteristics (*sensu* McAuley et al., 2007), such as slow growth, late age at maturity, small litter size and especially a long reproductive cycle, the species reproducing every two years off Senegal and in other marine areas (Casey et al., 1985; Brewster-Geisz & Miller, 2000; Saïdi et al., 2005).

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