REPRODUCTIVE CYCLE AND MIGRATION OF THE BLUE SHARK (*PRIONACE GLAUCA*) IN SOUTH ATLANTIC OCEAN

Jefferson F. A. Legat
Empresa Brasileira de Pesquisa Agropecuária, Embrapa Meio-Norte.
BR 343, km 35, Caixa Postal 341, Parnaíba-PI. CEP 64200-970. Brazil.
e-mail: legat@cpamn.embrapa.br

Carolus M. Vooren
Fundação Universidade Federal do Rio Grande, Laboratório de Elasmobrânquios e Aves Marinhas, Caixa Postal 474, Rio Grande-RS. CEP 96201-900. Brazil. e-mail: doccmv@furg.br

Abstract

A study conducted in Southern Atlantic Ocean, between 27°S and 35°S, and researches developed by several authors propose the existence of an annual reproductive cycle for the blue shark, *Prionace glauca*, in the South Atlantic Ocean. Coupling takes place during spring and summer. Ovulation and egg fertilization occur between March and April, followed by parturition 9 or 12 months later. The existence of two distinct populations was proposed for South Atlantic: Population I, between 5° N and 7° S; and Population II between 20° and 35° S. Coupling, ovulation, fertilization and pregnancy of Population II occur near the southeastern and southern Brazil. Parturition and nursery areas may be situated respectively at the southeastern central Atlantic and southeastern Atlantic regions. Population I accomplishes coupling and ovulation in the northeastern Brazil, and pregnancy and parturition near Africa.

Introduction

The blue shark *Prionace glauca* is abundant worldwide in the epipelagic zone of tropical, subtropical and temperate seas. Throughout its area of distribution, the species has been caught in increasing numbers since the early 1960's as bycatch or target species, in pelagic longline fisheries. In recent years the catch per unit effort has declined in several fishing areas. Due to its life characteristics the species is classified as especially vulnerable to overfishing (Castro *et al.*, 1999). Thus, there is an urgent need to manage the fishery. One of the requirements for

such management is to define reproductive cycle, unit stocks and migratory pattern.

P. glauca is viviparous, with a yolk-sac placenta. In the North Atlantic Ocean, reproductive cycle is annual. Coupling takes place during summer. Fertilization occurs in spring, followed by parturition 9 or 12 months later, young are born at a length of 35-50cm. After parturition, ovarian eggs are ready to another fertilization (Pratt, 1979).

In the North Atlantic, individuals have shown a regular clockwise trans-Atlantic migration pattern with the current system of that hemisphere. *P. glauca* rides the Gulf Stream to Europe, takes various currents in the European and African coast and returns to North America in the Atlantic North Equatorial Current (Hazin, 1993; NOAA ,1998).

In the southern Atlantic Ocean, Hazin *et al.* (2000) proposed an annual reproductive cycle. Coupling takes place between December and February. Ovulation and fertilization occur between February and April and parturition occurs next December and February. These authors proposed the existence of a single stock of *P. glauca* in the South Atlantic, with a clockwise migration as observed in North Atlantic. Females blue shark are supposed to copulate in Southern Brazilian waters during summer and then move to Northeastern Brazilian areas to ovulate and fall pregnant 4 months later. The pregnant females then move to African Coast and the parturition may occur at high latitudes. In this case, individuals don't follow the current system of South Hemisphere.

Previous studies in southern and southeastern Brazilian coast (lat. 20°S and 33°S and long. 39°W and 50°W) observed copulation, ovulation, fertilization, and pregnancy with embryos at different stages (Amorim, 1992; Guedes, 1999; Legat, 2001). These data indicated that blue sharks females of Southeast and Southern regions had the entire cycle except parturition at those areas and did not follow the theorized clockwise movement.

In this work we present a study of *P. glauca* reproduction in the Southern Atlantic Waters. According to these results and to researches developed by several authors, we propose the existence of an annual reproductive cycle and a new migration pattern for the blue shark in the South Atlantic Ocean.

Material and methods

This study was conducted at the "Laboratório de Elamobrânquios e Aves Marinhas da Universidade Federal do Rio Grande". The study area was the continental slope of southern Brazil, between lat. 27°S and 34°S, and long 46°W and 51°W (Figure 1). The samples were taken by R. V. "Atlântico Sul", using tuna longline. Longline was baited with squid, set at 5 pm, and retried at 9 am of the next day. Samples were distributed randomly over depths of 200 to 1000 m, with few samples over greater depths: 7 sets in November and December 1996, 11 sets in July 1997, and 10 sets in March and April 1998.

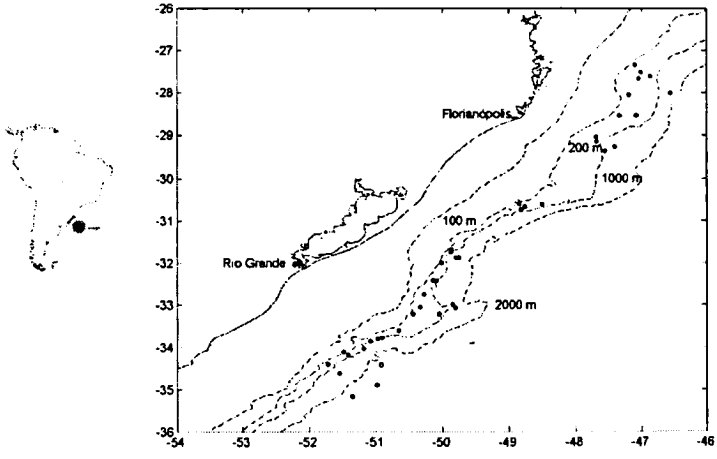

Figure 1.Study area between lat. 27°S and 34°S and long. 46°W and 51°W. Spots represent the longline sets.

A total of 227 blue sharks were caught, 60 females and 167 males. Data were collected immediately after capture. The total length (TL) was measured according to Compagno (1984). Weight of the body, liver and gonads were recorded. In males, clasper length was measured from the insertion to tip. For females, the following data were recorded: width of the nidamentary gland, width of the uterus, color and diameter of the largest ovarian follicle, presence of uterine eggs and embryos. In the 8 pregnant females caught, number of embryos, embryos TL and weight were recorded.

The presence of mating marks in female blue sharks is reported as copulation indicator (Stevens, 1974; Pratt, 1979; Hazin *et al.*, 1994). Wounds can be semicircular impressions, tooth slaches and individual tooth cut. Fresh mating injuries indicates copulation period (Stevens, 1974).

Statistical analyses were performed according to Campbell (1989) and to Sokal and Rohlf (1969).

Results and Discussion

In the southern Brazil, male blue shark reach maturity to start from 210 cm TL and all the individuals larger than 249 cm TL are adults ($p< 0,000$). The adult male has claspers larger than 15 cm, testis weightier than 200g and gonadosomatic indices higher than 0.4.

The blue shark females reach maturity in this region to start from 195 cm TL. At 215 cm TL, 50% of population is mature and all females larger than 240 cm are adult ($p< 0,000$).

Females were separated into the following sexual stages: Immature, (individuals smaller than 195 cm TL. Translucent uterine follicle, range from 0.4 to 0.7 cm diameter. Width of both nidamentary gland and uterus smaller than 2 cm); Subadult (females with TL between 197 and 240 cm; Nidamentary gland width bigger than 2.0 cm; Uterus width between 2.0 cm and 3.0 cm; Opaque or translucent ovarian follicles. These sharks are supposed to start the first reproductive cycle to enter the adult parcel of population); Adult (specimens with TL between 204 cm and 294 cm, nidamentary gland width larger than 2.0 cm, uterus width larger than 5.0 cm, presence of vitellogenic follicles larger than 1.0 cm diameter or presence of uterine eggs or embryos).

From these data and previous work from Grotenbreg and Vooren (1999) works, male reach maturity between 4 and 7 years and female between 3.5 and 7 years.

According to the results of this work and the studies from Amorim (1992), Hazin *et al.* (1994; 2000) and Guedes (1999), we propose the existence of an annual reproductive cycle for female blue shark in the South Atlantic Ocean (Figure 2) as descript bellow:

Mating occurs from November to March, mainly from December to February when females have vitellogenic follicles with 1.5 cm and 3.0 cm diameter. Ovulation and egg fertilization occur immediately after coupling in southern and southeast Brazilian waters. In northeastern Brazil, females ovulate and fall pregnant 3 months after mating. Thus, between the end of the summer and early fall, females blue shark have uterine eggs or embryos with TL ranging from 2.0 cm and 6.0 cm. From March to June, embryos grow to 10.0 and 25.0 cm TL. Embryos larger than 18.0 cm TL have placental connections with the uterine wall.

In the winter, embryos reach 25.0 to 30.0 cm TL. Females begin to produce translucent ovarian follicles between 0.2 cm and 0.5 cm diameter. In the spring, embryos from 30.0 to 35.0 cm TL and translucent or opaque follicles between 0.2 and 0.8 cm are observed. In the late spring, vitellogenic follicles up to 1.0 cm diameter are present.

In the following summer parturition occurs 9-12 months later. Embryos are full term with TL ranging from 35 to 50 cm. Females have vitellogenic follicles between 1.5 and 3.0 cm. After pupping, female reinitiate the copulation-ovulation-fertilization-gestation-parturition sequence.

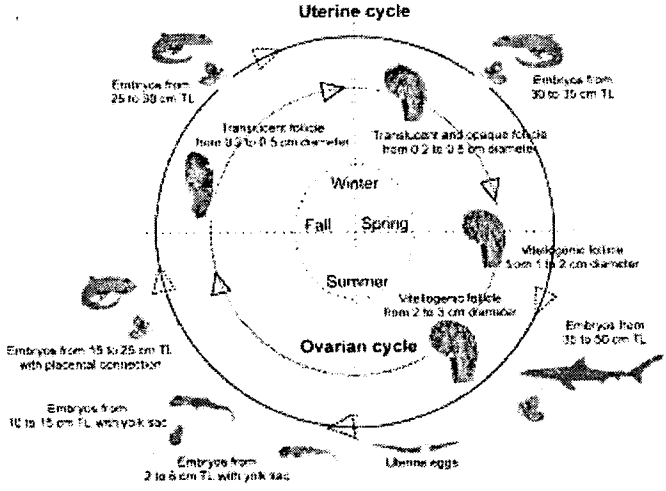

Figure 2. Reproductive cycle of female *Prionace glauca* in South Atlantic Ocean

According to this work and studies from Amorim (1992), Hazin *et al.* (1994; 2000), Castro and Mejuto (1995), Guedes (1999), and data from the "Instituto Nacional de Pesca, Montevideo, Uruguay", we propose the existence of two stocks of *P. glauca* in the South Atlantic Ocean. Population I in Equatorial region between lat. 5°N and 7°S and Population II between lat. 20°S and 40°S (Figure 3). Beside the studies cited, the migration pattern of the two populations agrees with the geostrophic currents of South Atlantic Ocean determinate by Stramma and England (1999).

The presence of mating, ovulation, fertilization and pregnant females with embryos at various stages of development at the southern and southeast Brazilian waters means that these females accomplish the entire reproductive cycle, except parturition, in the same region.

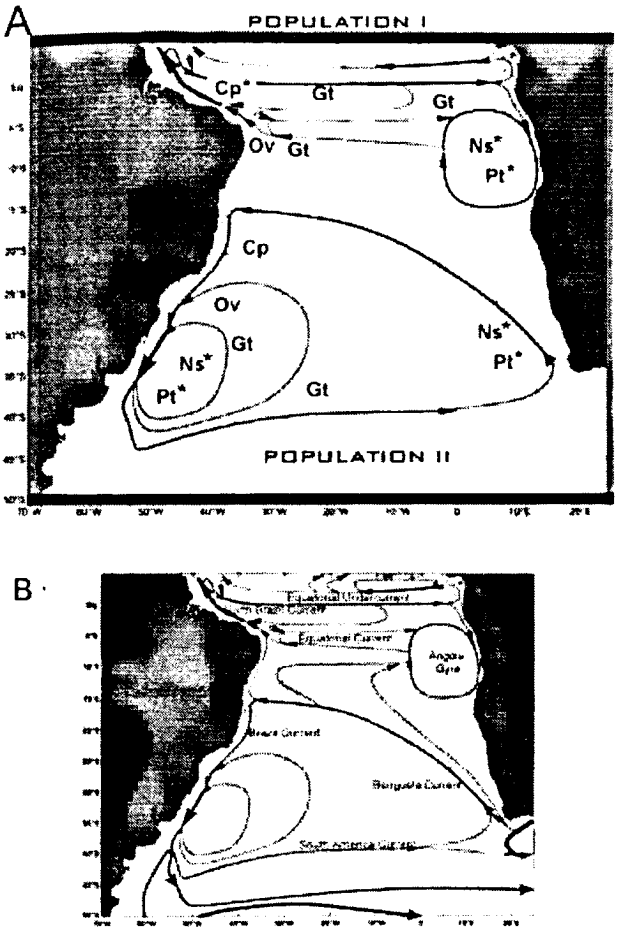

Figure 3. A: Proposed model of *Prionace glauca* migration in South Atlantic Ocean; Cp means copulation area, Ov ovulation area, Gt gestation area, Pt parturition area and Ns nursery area. Areas marked with an * are not confirmed. B: geostrophic currents of South Atlantic Ocean determinate by Stramma and England (1999).

In northeastern Brazil, lat. 2°S and 7° S and long. 32°W and 38° W, Hazin *et al.* (1994; 2000) observed ovulation, fertilization and gestation till embryos with 26.0 cm Fork length (FL). Those authors also observed mating scar at small scale in that region.

Castro & Mejuto (1995) collected pregnant female with embryos from 3.0 cm to 35 cm FL, between lat. 5° N and 5° S and long. 5° E and 5° W.

Hazin et al. (1994; 2000) suggest that female blue sharks copulate at southern Brazil and then move towards northeastern waters to ovulate about 3 months later. In this case, female must swim against the Brazil Current before start the ovulation and pregnancy and swim against the South Atlantic Current after parturition (Figure 3).

P. glauca is a placental viviparous shark. Placental species establish a utero-placental complex that supplies the embryo with nutrients and oxygen and removes wastes (Hamlett, 1997). In this way, movements with the stream become a form of maintaining energy for the gestation period.

Furthermore, in their study about movements of P. glauca, Carey and Scharold (1990) affirm that none of the sharks with attached transmitters appeared to be swimming against a current.

We proposed that in the population I, mating, ovulation, fertilization and initial stages of pregnancy occur at East region of South Atlantic Ocean, near northeastern Brazil. Females move towards the African waters while embryos developed. Parturition may occurs between lat. 5°N and 5°S and long. 5°E and 10°E, near the Angola Gyre (Figure 3).

In the theorized population II, mating, ovulation, fertilization and pregnancy occur between lat 20° S and 40° S. Although it was been observed full term embryos in pregnant females, it was not possible to determinate a particular area where parturition occurs. We propose that pupping area is located in Uruguay and Argentina waters. Nursery area probably is located in African waters between lat. 30° S and 40° S (Figure 3).

According to the migrate pattern proposed in this study, population I and II move following the geostrophic currents of South Atlantic Ocean. Population I moves with North Brazil Current, the South Equatorial Current, the Northern,

Equatorial, Central and Southern Branches and with the Equatorial Undercurrent. Population II moves with Brazil Current, Benguela Current and South Atlantic current. In this model, the species follow the current system to make a trans-Atlantic migration route as in North Atlantic Ocean.

Further study is required to determinate the parturition and nursery areas of both population and to determinate the major mating area of population I. Therefore, data from another South Atlantic regions will permits verify the existence of unit stocks in South Atlantic.

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