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Numerical population estimates update for Southern Right Whales in Brazil

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Southern right whales use the Brazilian coast as a wintering area. This population was severely depleted by the whaling until 1973. Since 1980s studies have showed that the species is now restricted to southern Brazil. Using photo-id data obtained from standardized aerial surveys from Florianópolis/SC (-27º.797/-48º.533) to Torres/RS (-29º.396/-49º.763), mark/recapture methods were used to estimate survival capture and recruitment probability, and population size using POPAN model, and population grow rate using PRADEL models. Data were collected in September from 2004-2018. The final model was selected by the lowest AIC. GOF tests were used to validate the models. It was tested differences among females (whales with a calf at least once in all dataset) and adults (males or female never spotted with calf) and the effect of time. It was identified 520 whales, 345 females and 175 adults. From the total, 40.58% of females and 3.55% of adults were recaptured at least once. The final POPAN model (AIC 1648.4025) fixed the survival in 0.99 for females and adults. Capture probability was different for females and adults having effect of time. Recruitment probability was the same form both classes and had effect of time. Population size was estimated in 569 (±38) for females and 2,626 (±737) for adults. The final PRADEL model showed that the population growth rate was the same and constant for females and adults (4.8% ±1.2%). GOFs tests did not indicated signal of response to capture (TEST2.CT: p=1) and there was no evidence of transiency (TEST3.SR: p=0.43). This is the first update of the population trends for Southern right whales in Brazilian breeding ground since 2010.

Introduction

Since the intense exploration by the whaling in southern Brazil, the lack of records of catches associated with no sightings of southern right whales from 1973, when it was recorded the last catch, until 1986, when the whaling was still legally in Brazil, indicates an extreme decline of the Brazilian right whale population (Palazzo & Carter 1983;). Since the early 1980s, this population has been systematically studied to follow the population trends. Aerial surveys using photo identification has been conducted since 1986. Currently the species occurs mainly in the southern coast of Brazil, highlighting Santa Catarina State. The area is known as a breeding ground for species (Groch *et al.*, 2005; Seyboth *et al.*, 2015; Renault-Braga *et al.*, 2018; Renault-Braga *et al.*, 2021).

In 2005 the population grow rate was estimated in 14% per year using linear regression of identified females per year. Later, a population grow rate was updated to 12%

analyzing a mark-recapture dataset from 1987 to 2010. This same study estimated the reproductive female population in 200 whales (IWC, 2012).

In the present study we update these numbers modeling population demographic parameters of the southern right whales that breed in the southern Brazilian coast. For this analysis, we used a 15 years dataset (from 2004 to 2018), and mark recapture models. Once there is some overlap between right whales wintering in Brazil and Argentina (about 13% of whales photoidentified in Brazil were also recorded at least once in Argentina) (Best *et al.,* 1993; Groch 2018; Rowntree *et al,* 2020), and high genetic homogeneity in nuclear DNA between these whales (Ott 2002), we have to choose models that deal with this relationship, and consider the Brazilian right whale population an open population. Southern right whales are classified as "least concern" by the IUCN red list, but locally the specie is classified as "endangered". Our work updates information for this important breeding ground for the species.

Methods
Systematic aerial surveys were conducted from 2004 until 2018 aimed in right whales photo identification. The surveyed area was from Florianópolis/SC (-27,797 lat/-48.533 long) to Torres/RS (-29.396 lat/-49.763 long), the main occurrence area of the species in Brazil (Renault-Braga et al., 2018). Data were collected by trained observers, per standardized survey protocols (see Renault-Braga et al., 2018; Renault-Braga et al., 2021) and a helicopter (Bell Jet Ranger). Survey tracks were 500 m off and parallel to the coastline at a mean speed of 100 km/h and an altitude of 300 meters. It was attempted to survey only on days with the optimal conditions of low wind speeds (<10 knots), low sea states (≤3 Beaufort Sea Scale), adequate lighting (8:00 to 16:00), and good visibility (horizon line visible).

Individual identification from natural marks was based on callosity patterns of the head, and, unusual pigmentation along the body (used as secondary factors to confirm the identification). Only high-quality photo (considering brightness, focus, contrast and a satisfactory angle) were used in this study to ensure that all matches are correct. The software "Right whale photo-identification" (Hiby and Lovel, 2001) was used to analyze the photographs.

The POPAN model, a derivation of the Jolly-Sober model, was used to estimate the survival (φ), capture probability (p), recruitment probability (pent), and population size (n) for open populations. This approach was widely used for right whales populations (Carroll *et al.,* 2011; Wade *et al.,* 2011; IWC 2012; Carroll *et al.,* 2013; Jackson *et al.,* 2016). To update the population growth rate (λ) we used PRADEL model (Pradel, 1996). It was tested differences among classes (females – whales with a calf at least once in the dataset; referenced in model as FE, and adults – males or female never spotted with calf; referenced in model as AD) and the effect of time (t= affected by time; . constant). We also tested to fix the survival parameter in 0.99 (plausible values as describe by Carroll *et al.*, 2011). The models were analyzed at MARK 9.0 software. The final model was selected using the AIC (Akaike Information Criterion). We used the software U-CARE

V.2.3.4 (Choque *et al.*, 2009) to test for the behavioral response to the capture (TEST2.CT) and to test the presence of transients (TEST3.SR) (GOFS tests).
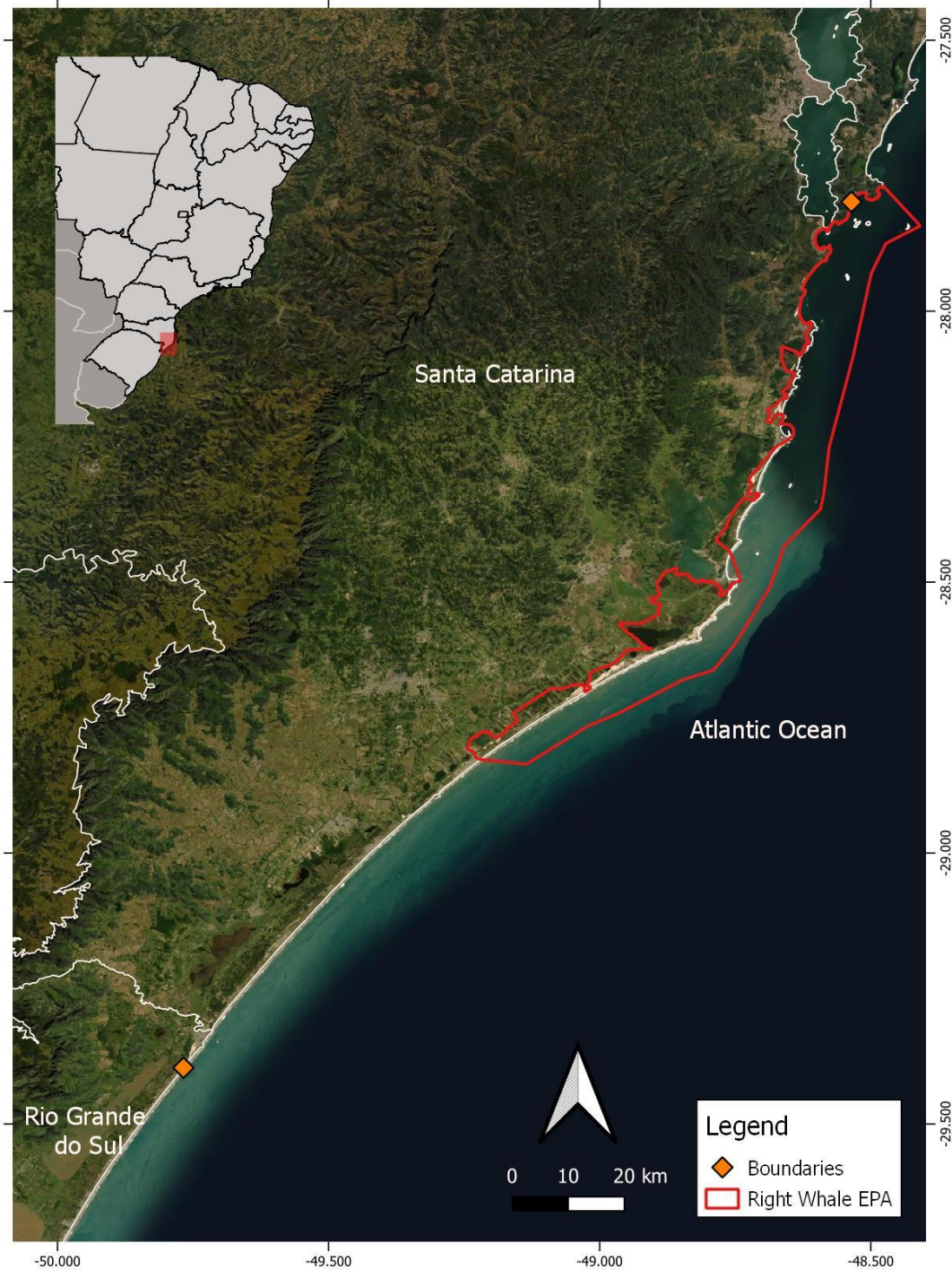
Study Area

Figure 1. Study area of the surveys conducted from 2004 until 2018 in Santa Catarina State, southern of Brazil.

Results and Discussion

It was identified 520 whales, consisting of 345 females and 175 adults. From the total, 40.58% of females were recaptured at least once, while only 3.55% of adults were recaptured at least once.

The three best fitted POPAN models were described in table 01. The final POPAN model (AIC 1648) fixed the survival in 0.99 for females and adults. Capture probability was? different for females and adults having effect of time. Recruitment probability was the same for both classes and also presented effect of time. The selected model estimates are described in figure 02.

Table 1. Three best fitted POPAN models to describe population trends in southern right whales in southern Brazilian coast.

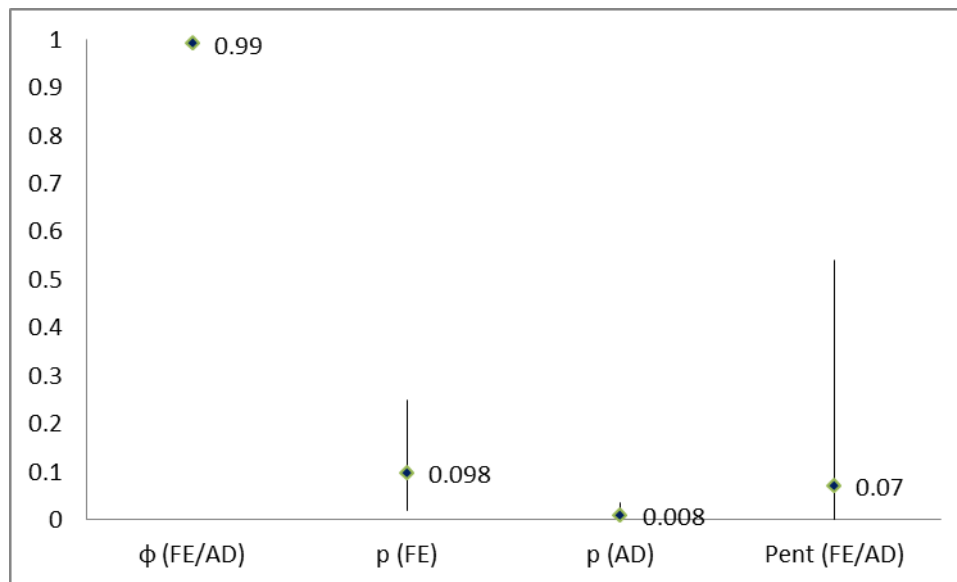| Model	AIC	Deta AIC	AIC weight
φFE=φAD(0.99) pFE(t)≠pAD(t) pentFE=pentAD(t) nFE(.)≠nAD(.)	1648*	0	0.99
φFE(0.99)≠φAD(t) pFE(t)≠pAD(t) pentFE(t)≠pentAD(t) nFE(.)≠nAD(.)	1658	10	< 0.01
φFE(.)≠φAD(.) pFE(t)≠pAD(t) pentFE(t)≠pentAD(t) nFE(.)≠nAD(.)	1696	47	< 0.01
* selected model in bolt			

Figure 2. Fixed parameters of survival (**φ**), estimated capture probability (p) and recruitment probability (pent) for females (FE) and adults (AD) of southern right whales in southern Brazilian coast.

As in other breeding areas the best fitted models select the fixed survival value for both classes (Carrol et al., 2011). The differences in capture probability are also expected once females use the breeding ground in regular intervals, differently from adults (Groch *et al.*, 2005). Also, it was expected that the capture and recruitment has effect of time once there

are fluctuations in right whales abundance in breeding grounds due the triennial reproductive cycle of the specie (Best *et al.*, 2001; Cooke *et al.,* 2001; Groch *et al.*, 2005).

The population size (n) was estimated in 569 (±38) for females and 2,626 (±737) for adults. We consider that the estimates for adults have to be used carefully due to the low recapture rates.

Once the survival and capture probability was already estimated in POPAN model, we only considered the population growth in PRADEL models. The best fitted model describes that the population growth rate is the same for both classes and have no effect of time (table 2).

Table 2. Three best fitted PRADEL models to describe population trends in southern right whales in southern Brazilian coast

Model	AIC	Deta AIC	AIC weight
φFE(.)≠φAD(.) pFE(t)≠pAD(t) λFE (.)=λAD(.)	*3920**	*0*	*0.66*
φFE(.)≠φAD(.) pFE(t)≠pAD(t) λFE (.)≠λAD(.)	3922	1.4	0.33
φFE(.)=φAD(.) pFE(t)≠pAD(t) λFE (.)=λAD(.)	3941	20.9	< 0.01
* selecte model in bolt			

The Brazilian southern right whale population was estimated to have a growth rate of 4.8% (±1.2%) per year. Our results are closer to the population grow rates of other areas when compared with the oldest estimates. South Africa describes estimates of 6.9%, Argentina 6.0%, Australia 6.79% and New Zealand 7% (Bannister 2010; Brandão *et al.*, 2010; Carrol *et al.*, 2013, IWC 2012). A population growth rate estimated higher than 11.8% was considered not biologically plausible for humpback whales (Brandão *et al.,* 2000; Clapham *et al.*, 2001; Zerbini *et al.*, 2010). Despite there is no estimates of such value for right whales, we believe that once the species has higher reproductive intervals compared with humpback whales, this estimates is also valid for right whales.

GOFs tests do not indicate signal of response to capture (TEST2.CT: p=1) and there was no evidence of transiency (TEST3.SR: p=0.43) indicating a good fit of the models.

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