Received Date : 27-Jun-2015

Revised Date : 26-Feb-2016

Accepted Date : 15-Mar-2016

Article type : Review

REVIEW

From the southern right whale hunting decline to the humpback whaling expansion: a review of whale catch records in the tropical western South Atlantic Ocean

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ABSTRACT

1. Historical catch records from whaling activity are crucial for assessments of whale populations. However, several gaps in the exploitation history for many populations from before the twentieth century create limitations that may lead to overestimates of the recovery of these populations. The history of modern whaling along the Brazilian coast is relatively well known. However, several questions relating to the pre-modern period, during and before the nineteenth century, remain unanswered. For example, the level of exploitation of humpback whales *Megaptera novaeangliae* and southern right whales *Eubalaena australis* in this period is unknown.
2. Pre-modern whaling in Brazil began in 1602 and lasted until the 1920s. Whales were captured using manual harpoons from either rowing boats or sailing boats, and processed at land stations called 'armações'. A review of the history and oil production of these stations indicates that substantial catches occurred.
3. Pre-modern whaling records also indicate the collapse of the southern right whale population in the western South Atlantic Ocean. Increasingly rare reports of sightings for the nineteenth century and the closing of the last armação in the breeding grounds off southern Brazil indicate that this population collapsed by 1830.
4. Armações operating in north-eastern Brazil remained active through the 1800s, and targeted humpback whales until modern whaling techniques were introduced in the early 1900s. It is estimated that between approximately 11000 and 32000 individuals of this species were captured at these coastal whaling stations from 1830 to 1924.

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Key words: Brazilian coast, *Eubalaena australis,* exploitation, *Megaptera novaeangliae*, whalers.

Running head: Humpback whaling in the western South Atlantic Ocean.

Submitted: 27 June 2015

Returned for revision: 21 September 2015

Revision accepted: 15 March 2016

Editor: KH/DR

INTRODUCTION

Historians usually divide whaling history into two main periods: pre-modern or traditional whaling (Ellis 2002), and modern whaling (Clapham & Baker 2002). The distinction between these periods is based mainly on the techniques used to capture the animals. Manual harpoons and rowing boats and/or sailing boats launched from the beach or from sailing ships were typical characteristics of whaling in the pre-modern period. This lasted until the early twentieth century, when the advent of the harpoon gun and steam vessels heralded the start of the modern whaling era (Ellis 1991).

In Brazil, whaling began in 1602 when the Portuguese Crown granted a permit for hunting whales on the coast of Bahia state (BA) for ten years to two whalers from the Basque region of Europe (Ellis 1969). However, whaling did not stop within these ten years, but lasted until 1985 when the International Whaling Commission moratorium was implemented (Anonymous 1983, Smith 1984). Subsequently, in 1987, whale catches were prohibited indefinitely within Brazilian waters by federal law (Palazzo & Palazzo Jr. 1989). Despite spanning almost four centuries of operation, there is little information on whaling along the coast of Brazil, especially in the pre-modern period. For example, quantitative data on the number of whales killed before the early 1900s are still poorly known.

It is widely accepted that Brazilian whalers began their activities by exploiting the breeding stock of southern right whales *Eubalaena australis* found in or near Baía de Todos os Santos (12°48'S, 38°38'W), in BA, during the seventeenth century (Palazzo & Palazzo Jr. 1989, Hetzel & Lodi 1993, Richards 1993, Greig et al. 2001, Palazzo Jr. et al. 2007, Richards 2009, Edmundson & Hart 2014). Southern right whales exhibit coastal habits in the breeding grounds, frequently using shallow waters of up to 5 m in depth (Payne 1986). This peculiarity, coupled with their slow swimming and characteristic floatability after death (Scammon 1874), facilitated the hunting by whalers from coastal whaling stations – or 'armações' as they were known in colonial Brazil (Ellis 1969, Castellucci Jr. 2009). Whaling techniques employed at

these stations were similar to those used by the Basques in Europe (Reeves & Smith 2006). The hunt began with 4 or 6 rowing and sailing boats being launched from the beach and could extend 18 to 25 km along the coast, depending on the location of whales. Whales were captured and killed by manual harpoons and were towed by the same boats for processing in the armação (Ellis 1969).

The pre-modern whaling techniques used at the armações imposed restrictions on the species that could be captured by the whalers. In addition to southern right whales, only two other species could be exploited in Brazil: humpback whales *Megaptera novaeangliae* and sperm whales *Physeter macrocephalus* (Lodi 1992, Toledo & Langguth 2009, Ellis 2011). The only record of sperm whales being processed at armações was of six individuals captured by the North American brig Leviathan (Ellis 1969). This ship was seized in 1773 by Portuguese authorities near Guanabara Bay, in Rio de Janeiro state (RJ), and its crew was forced to set sail again and demonstrate their techniques for hunting whales and refining spermaceti oil to the colonists. Ellis (1969) reports that, despite the enthusiasm of the provincial governor, the Portuguese Crown was not interested in continuing the capture of sperm whales.

Humpback whales could be captured using pre-modern techniques because of their preference for shallow and coastal waters, and their relatively slow swimming speed compared to that of other Balaenopterids (Allen 1980, Mitchell & Reeves 1983). The first records of humpback whaling date back to the sixteenth century in the North Atlantic (Mitchell & Reeves 1983). In Brazil, the species was captured using pre-modern techniques along the coast (Ellis 1969, Lodi 1992) and in the waters surrounding the archipelago of Fernando de Noronha (3°51'S, 32°25'W; Lodi 1994). Once modern whaling initiated in the Southern Hemisphere, humpback whales were heavily exploited in the western South Atlantic, not only in their breeding grounds off Brazil, but also in feeding grounds in the surroundings of South Georgia and the South Sandwich Islands (Tønnessen & Johnsen 1982, Hart 2001, Zerbini et al. 2006, 2011a).

Whale catches were relatively large during pre-modern whaling on the Brazilian coast (Tavares 1916, Ellis 1969). However, the time periods in which captures of southern right whales and/or humpback whales started or ended and how many catches occurred during these periods is unclear (Palazzo & Palazzo Jr. 1989, Ellis 1969, Lodi 1992, Richards 1993, Lodi 1994, Palazzo Jr. et al. 2007, Richards 2009).

The assessment of population status is essential to establish conservation actions for exploited wildlife (Burgman et al. 1993). For whale stocks, gaps in whaling records limit our ability to assess their conservation status, and incomplete catch records lead to unrealistically low estimates of depletion levels (e.g. Zerbini et al. 2011b). For the western South Atlantic

humpback whale stock (known as "breeding stock A" in the International Whaling Commission's literature; Anonymous 1998, 2011), these gaps include catches made during pre-modern whaling years and between 1929 and 1946, a period in which the catch data in the breeding grounds are incomplete. A recent assessment of western South Atlantic humpback whales did not incorporate these missing catches and may have produced biased estimates of depletion levels for this stock (Anonymous 2007, Zerbini et al. 2011b).

Pre-modern catch data have been reconstructed by establishing a relationship between whaling stations' history (including location, opening and closing dates, and oil production) and the distribution of the species hunted along the coast (e.g. Mitchell and Reeves 1983, Best 1987). In this study, we review the history of whaling in the armações located along the coast of Brazil, based on a review of the literature and historic whale catch archives. We associate this information with the distribution patterns of humpback and southern right whales off Brazil, and suggest a time period for the collapse of the southern right whale population and the beginning of more extensive humpback whaling. We also provide an estimate of catches of humpback whales during the pre-modern whaling period.

HUMPBACK AND SOUTHERN RIGHT WHALE DISTRIBUTION OFF THE BRAZILIAN COAST

Humpback whales and southern right whales use the waters off the Brazilian coast as breeding and calving grounds. Historical information on their distribution in this region derives primarily from whaling data (e.g. Townsend 1935, Watase 1961, Hinds 1965, Grangeiro & Paiva 1965, 1970, Moura 1972, Smith et al. 2012). Contemporary data only became available when dedicated studies were conducted (Castello & Pinedo 1979, Pinedo 1985, Siciliano 1995, Lodi et al. 1996, Martins et al. 2001, Santos et al. 2001, Zerbini et al. 2004, 2006, 2011a, Groch et al. 2005, Andriolo et al. 2010a, 2010b), and today the two species are the best studied baleen whales (Mysticeti) in Brazilian waters.

Currently, the breeding season of southern right whales in Brazil extends from May to December (Groch et al. 2005), and during this period the animals can be observed from BA (12°S) to Rio Grande do Sul state (RS; 32°S; Greig et al. 2001, Santos et al. 2001). However, their main area of concentration is off the coast of Santa Catarina state (SC), particularly between south of Florianópolis (27°25'S, 48°30'W) and the Cape of Santa Marta (28°36'S, 48°48'W; Groch et al. 2005).

The humpback whale breeding season off Brazil is similar to that of the southern right whale, and typically lasts from early June to early December (Siciliano 1995, Martins et al.

2001). The distribution of humpback whales is quite different; they occur mainly between Rio Grande do Norte state (RN; ~5°S) and RJ (21-23°S; Zerbini et al. 2004, Andriolo et al. 2010b), and higher densities are found along the coasts of BA and northern Espírito Santo state (ES; Andriolo et al., 2010b). Unlike southern right whales, humpback whales have also been recorded around oceanic islands off the Brazilian coast (Lodi, 1994; Siciliano et al., 2012; Wedekin et al., 2014).

WHALING HISTORY AND CATCHES IN THE ARMAÇÕES

While various authors have reported on pre-modern whaling catches off Brazil (e.g. Townsend 1935, Ellis 1969, Richards 1993, 2009, Smith et al. 2012), the book by Myriam Ellis (1969) is the main source of information on whales taken from the armações, which existed in the states of Rio de Janeiro (RJ), São Paulo (SP) and Santa Catarina (SC) in southern Brazil, and in the state of Bahia (BA) in north-eastern Brazil (Figure 1).

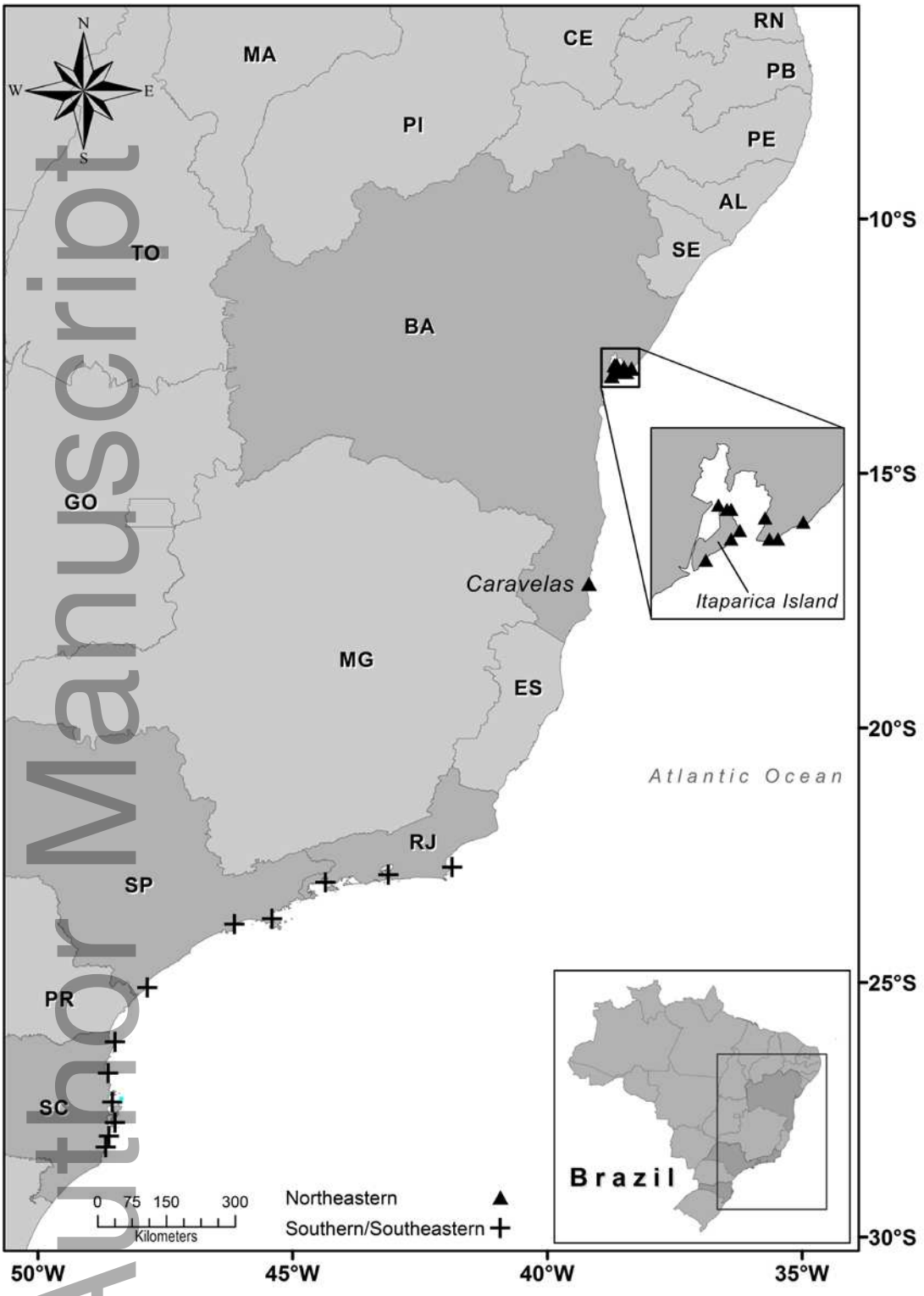

Figure 1. Map showing the locations of armações (whaling stations, shown as ▲ and +) along the Brazilian coast (see Table 1 and the text for details on the periods of operation of each individual whaling station). Brazilian states are abbreviated as follows: TO = Tocantins, MA = Maranhão, PI = Piauí, CE = Ceará, RN = Rio Grande do Norte, PB = Paraíba, PE = Pernambuco,

AL = Alagoas, SE = Sergipe, BA = Bahia, GO = Goiás, MG = Minas Gerais, ES = Espírito Santo, RJ = Rio de Janeiro, SP = São Paulo, PR = Paraná, SC = Santa Catarina.

The first attempts to implement shore-based whaling activities along the Brazilian coast date back to 1587, but organized whaling began on 9 August 1602, when Philip III of Portugal granted permission to two Basque whalers to hunt whales in the Baía de Todos os Santos (BA; De Souza 1851, Ellis 1969). The first armação was established at Ponta da Cruz, on Itaparica Island, at the entrance of the Baía (Castellucci Jr. 2009). In 1614, whaling off Brazil became a monopoly of the Portuguese crown, resulting in an expansion of the armações southwards along the Brazilian coast. The first in RJ was established around 1620 and was followed by others along the coasts of SP in 1734 and SC in 1746 (Ellis 1969, Edmundson & Hart 2014). Armações near Caravelas (BA) were only established in 1847, because local authorities believed whales were not abundant in the region (Castellucci Jr. 2009). At the middle of the eighteenth century there were between 24 and 29 armações operating in Brazil (Ellis 1969; Table 1).

Table 1. Armações on the Brazilian coast with their states, geographic coordinates, opening and closing years, and sources of information.

Armação	State*	Coordinates	Year opened	Year closed	Source
Ponta da Cruz	Bahia	13°05'S, 38°44'W	1602-1614	~1801	Ellis (1969)
Ponta de Itaparica	Bahia	12°52'S, 38°41'W	1612	~1801	Ellis (1969)
Pituba	Bahia	13°00'S, 38°27'W	1614-1763	~1801	Ellis (1969); Castellucci Jr. (2009)
Rio Vermelho	Bahia	13°00'S, 38°29'W	1614-1763	~1801	Ellis (1969); Castellucci Jr. (2009)
Pedra Furada	Bahia	12°55'S, 38°30'W	1614-1763	~1801	Ellis (1969); Castellucci Jr. (2009)
Manguinhos	Bahia	12°53'S, 38°38'W	1614-1763	1920	Ellis (1969); Edmundson & Hart (2014).
Porto Santo	Bahia	12°53'S,	1614-	1920	Ellis (1969);

		38°39'W	1763		Edmundson & Hart (2014).
Gamboa	Bahia	12°58'S, 38°36'W	1614-1763	~1801	Ellis (1969)
Barra do Gil	Bahia	13°00S, 38°38'W	1614-1763	1920	Ellis (1969); Edmundson & Hart (2014).
Itapoã	Bahia	12°56'S, 38°21'W	1754-1760	1767	Ellis (1969)
Caravelas**	Bahia	17°43'S, 39°11'W	1847	1924 or 1929	Paiva (1965); Lodi (1992)
São Domingos	Rio de Janeiro	22°53'S, 43°07'W	~1620	1816	Ellis (1969)
Ilha Grande	Rio de Janeiro	23°08'S, 44°14'W	~1620	1816	Ellis (1969)
Cabo Frio	Rio de Janeiro	22°44'S, 41°52'W	1740	1767-1768	Ellis (1969)
Ilha da Gipóia	Rio de Janeiro	23°02'S, 44°21'W	1729-1734	1816	Ellis (1969)
São Sebastião/Ilha Bela	São Paulo	23°45'S, 45°24'W	1734	1826	Ellis (1969)
Bertioga	São Paulo	23°51'S, 46°08'W	1748	1826	Ellis (1969)
Ilha do Bom Abrigo	São Paulo	25°06'S, 47°51'W	1750-1765	1826	Ellis (1969)
Nossa Senhora da Piedade	Santa Catarina	27°21'S, 48°32'W	1746	1819	Ellis (1969)
Lagoinhas	Santa Catarina	27°45'S, 48°29'W	1772	1819	Ellis (1969)
Itapocoróia	Santa Catarina	26°47'S, 48°37'W	1778	1829	Ellis (1969)
Ilha da Graça	Santa Catarina	26°10'S, 48°29'W	1807	1829	Ellis (1969)

Garopaba	Santa Catarina	28°01'S, 48°36'W	1793-1795	1829	Ellis (1969)
Imbituba	Santa Catarina	28°14'S, 48°40'W	1796	1829	Ellis (1969)

*'States' have been known as Capitania (to 1821), Province (to 1889), and State (post-1889).

**Paiva (1965) and Lodi (1992) record the existence of six different armações in this locality.

There is no precise information regarding the number of whales captured at the armações since the beginning of their operation until the end of the eighteenth century. Ellis (1969) suggests an annual capture of 200 to 500 animals per armação in SC between 1761 and 1775, but no numbers are provided for other states (e.g. SP, RJ and BA) or other years.

By the late eighteenth and early nineteenth century, some significant changes in the operations of the armações became evident: their expansion had ceased and whales had become scarce, leading to financial losses caused by the dramatic decrease in the catches (Ellis 1969). At each armação in SC, approximately 37 whales were captured per year between 1793 and 1796. This number dropped to 9 in 1819, a big change from the 200–500 annual catches per armação reported during 1761-1775. Low catches in the early 1800s resulted in the closure of the armações in RJ, SP and SC by 1829 (Ellis 1969; Table 1).

As of 1830, only the nine armações in BA continued to operate (Table 1): three on Itaparica Island and the other six in the municipality of Caravelas (Paiva 1965, Lodi 1992; Figure 1). There are no precise catch records for the armações in BA until they closed in the 1920s. Furniss (1909) and Ellis (1969) report, respectively, annual captures of 300–400 and 120–200 animals in BA during the nineteenth century, but it is not clear if these numbers reflect the overall catches for all armações or an average for each armação. Additionally, Tavares (1916) reports that nearly 200 whales were killed per year in all of BA at the beginning of the twentieth century.

In the armações in Itaparica, pre-modern techniques were used until 1911, when the Duder and Brother Company bought two whaling ships from Norway. This marks the beginning of the modern whaling period in Brazil (Tavares 1916, Edmundson & Hart 2014). According to Tavares (1916), the introduction of modern techniques almost ended to the use of sailing and rowing boats for hunting; they were used solely for towing captured animals for processing. Harpoon-guns were used by the whalers from these armações until 1920, when Duder and Brother ceased their involvement with whaling (Edmundson & Hart 2014).

Despite the introduction of modern whaling methods in Baía de Todos os Santos, pre-modern techniques continued to be used in the six armações operating from Caravelas (BA)

(Paiva 1965, Lodi 1992). The number of catches and the timing of the end of whaling activities in this region are a matter of debate. Paiva (1965) and Lodi (1992) agree that only one whale was caught during the last season in Caravelas. However, Paiva (1965) indicates that this event happened on 28 September 1924 while Lodi (1992) suggests that whaling ended in 1929. The average number of whales captured in the early twentieth century ranged from about 30 to 50 whales per year (Tavares 1916, Lodi 1992). Tavares (1916) indicated that these numbers are low compared to captures in previous years, but he does not provide a figure for catches taken prior to 1903.

When whaling ceased at Caravelas in the 1920s the nearly 320 years of the pre-modern hunting period in Brazil came to an end. Whaling using modern techniques, which began in the armações of Itaparica in 1911, expanded through the establishment of two whaling stations in Paraíba state (PB) and RJ respectively (Watase 1961, Hinds 1965, Paiva & Grangeiro 1965, Paiva & Grangeiro 1970, Williamson 1975, Edmundson & Hart 2014). The former operated until the whaling moratorium was imposed by the International Whaling Commission in 1985; the latter operated from 1960 to 1963 (Edmundson & Hart 2014).

IDENTITY OF SPECIES TAKEN AT THE ARMAÇÕES

The identity of the whale species taken at each of the armações is not well described and may have changed from the 1600s to the early 1900s in some places. The techniques used by whalers only allowed the capture of southern right whales, humpback whales and sperm whales. Because of the coastal nature of the fisheries and the lack of interest of the Portuguese crown in sperm whales (Ellis 1969), it is likely that catches made at the armações were comprised mainly, if not exclusively, of southern right whales and humpback whales.

It is generally accepted that primarily southern right whales at the armações in southern Brazil. Ellis (1969) distinguishes species in catches only once in her book, where she indicates that 160 “whales” and three “humpback whales” were captured at seven armações in SP and SC in 1801 (Ellis 1969, p. 173). In the reminder of her text, all catches are described as “whales”, without reference to any particular species. Subsequent researchers have assigned catches of “whales” reported by Ellis (1969) to southern right whales, but no additional evidence to confirm species identification has been provided (e.g. Câmara & Palazzo Jr. 1986, Richards 1993, Groch et al. 2005, Richards 2009).

It is likely that southern right whales did indeed represent the bulk of the catches at the armações in southern Brazil. This species was historically abundant in the region during winter and spring, and was found not only in coastal habitats, but also in more offshore

habitats where it had been observed or killed by the Yankee (North American) whalers at that time (Townsend 1935, Smith et al. 2012). In addition, recent data on seasonal distribution suggest that southern right whales, particularly mothers with calves, are regularly found from RJ to RS and are relatively more abundant off SC (Simões-Lopes et al. 1992, Lodi et al. 1996, Greig et al. 2001, Santos et al. 2001, Groch et al. 2005).

The exploitation of humpback whales by armações in southern Brazil does not seem to be widely acknowledged. While contemporary distribution patterns of humpback whales do not typically include coastal waters off southern Brazil (Zerbini et al. 2006, Andriolo et al. 2010b), historical records indicate that this species may have been present in middle-latitude coastal waters of eastern South America, including off southern Brazil, during winter and spring (Townsend 1935, Smith et al. 2012). It is therefore possible, as indicated by Ellis (1969, p. 173), that humpback whales may have comprised a fraction of the catches from armações in RJ, SP and SC.

Many authors indicated that southern right whales were also represented in large numbers in the catches from the armações in north-eastern Brazil (Peterson 1948, Câmara & Palazzo Jr. 1986, Richards 1993, Groch et al. 2005, Richards 2009), but no unambiguous description of the species taken in BA was provided until the late 1800s. At that time, catches clearly appear to be of humpback whales, not southern right whales. For example, Câmara (1937, p. 209) described the hunt carried out in boats from Itaparica in 1888 and mentions that: "There are many areas on the body where the harpoon should not be thrown because it skids and breaks upon penetration. This always happens between the dorsal fin and the tail". In addition, Tavares (1916) indicated that whales captured off BA in the early 1900s had short baleen plates and long pectoral fins (3.5 m in length). The presence of a dorsal fin and relatively long fins clearly suggests that these whales caught near Itaparica were humpback whales. This is further supported by a photograph of a dead humpback whale at an armação in Itaparica in the early twentieth century (Furniss 1909; Figure 2).

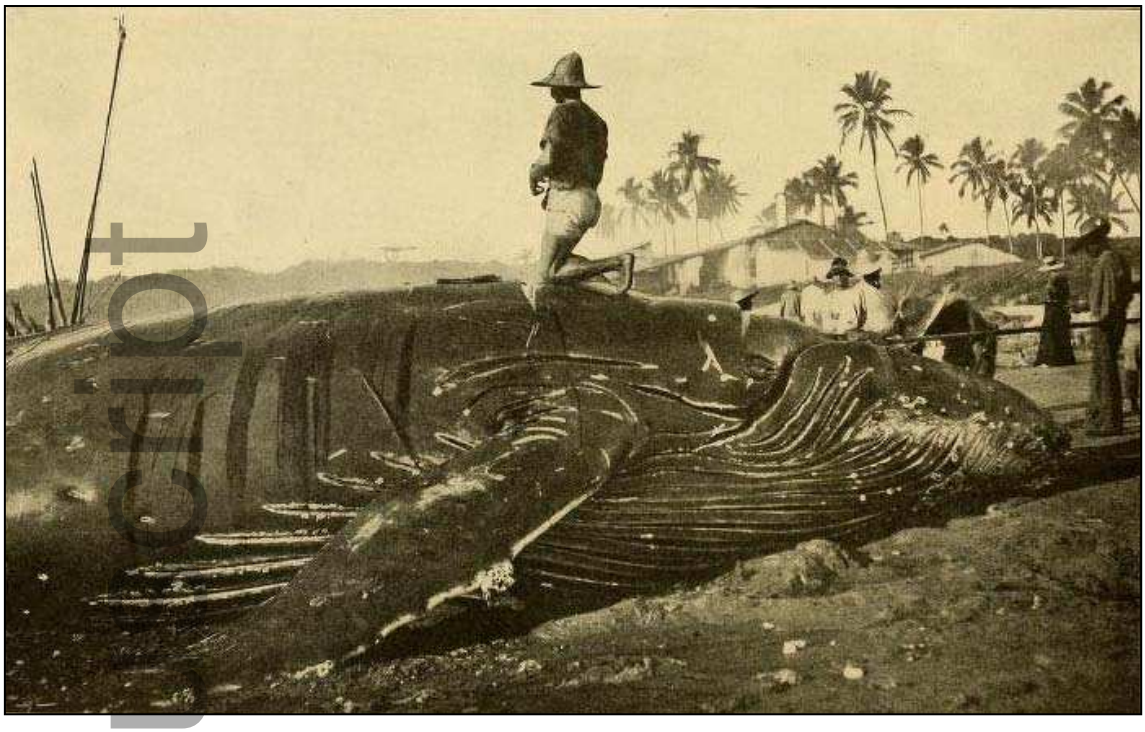

Figure 2. A humpback whale being hoisted for processing to the armação at Itaparica, Brazil, at the beginning of the twentieth century (reproduced from Furniss 1909).

The only evidence of the presence of southern right whales in coastal waters off north-eastern Brazil during the pre-modern period comes from two individuals found ashore, not hunted, in Baía de Todos os Santos in 1580 (De Souza 1851). These whales had "mouths large enough for a man to get stuck between one cheek and another, cutting with the axe on the lower lip with both hands without touching the upper lip", and "the lower lip stood out more than the one above". Such characteristics are distinctive for southern right whales, in which the arched lower jaw forms a very pronounced curve in the mouth (Kenny 2002).

It is possible that southern right whales were targeted by armações in north-eastern Brazil between the early 1600s and the early 1800s, as proposed by some authors (Palazzo & Palazzo Jr. 1989, Hetzel & Lodi 1993, Richards 1993, Greig et al. 2001, Palazzo Jr. et al. 2007, Richards 2009, Edmundson & Hart 2014). However, the historical presence of this species in this region is inconsistent with their current distribution along the coast of Brazil. The majority of southern right whale sightings and strandings since the 1980s have occurred to the south of Abrolhos Bank (~18^{o}S; Engel et al. 1997, Netto & Di Beneditto 2008). In addition, except for the records regarded as southern right whales from the armações in north-eastern Brazil, for which accurate species descriptions are not available, there are no historical records of southern right whales as far north as north-eastern Brazil, for instance from Yankee whalers operating further offshore (e.g. Townsend 1935, Richards 2009, Smith et al. 2012). Southern

right whales may not occur in large numbers off north-eastern Brazil today, because historical habitats may have not yet been re-occupied by the recovering population. It is also possible that their historical distribution in that region was very coastal, which would explain why the Yankee whalers operating further offshore were not catching them. However, there is no clear evidence that southern right whales were abundant enough off north-eastern Brazil to sustain catches of several dozen to a few hundred animals every year in the 1600s and 1700s.

The distribution of other southern right whale populations also provides no evidence of large breeding aggregations as far north as the location of the armações in north-eastern Brazil. Carroll (2014) indicated that the northernmost sightings of southern right whales off the Australian coast occurred at just over 30°S. Best (1981) and Weir (2010) reported that an aggregation of this species further north in south-western Africa was located in Baía dos Tigres (16°37'S), Angola, and that only a few individuals were captured occasionally above this latitude. A similar historical distribution pattern was documented for the Pacific coast of South America, where the Yankee vessels did not record any southern right whale catches north of 30°S in the nineteenth century. In addition, there are only six records of southern right whales in lower latitudes (e.g. off the coast of Peru between 17°38'S and 12°24'S) in the whole of the twentieth century (Waerebeek et al. 1992, Richards 2009, Vernazzani & Cabrera 2014).

It seems likely that humpback whales, which were historically and are currently present in north-eastern Brazil in relatively large numbers, may have represented a portion, perhaps a significant portion, of the catches taken by the armações in BA prior to 1830.

COLLAPSE OF THE SOUTHERN RIGHT WHALE POPULATION OFF BRAZIL – THE PREDOMINANCE OF HUMPBACK WHALE CAPTURES

In the early 1800s, catches of whales by the armações in southern Brazil had diminished considerably. Ellis (1969) reports a progressive decrease in the number of whales captured from SC, in a region currently known as a breeding or calving ground for the southern right whale (e.g. Câmara & Palazzo Jr. 1986, Groch et al. 2005); 133 animals were captured per armação in 1785, 23 in 1801, and only nine in 1819. This resulted in a crisis in oil production, leading to the importation of this product supported by reduced importation taxes. Whaling was no longer commercially viable in southern Brazil, and armações began to close one after the other. Those in RJ were closed by 1816, followed by those in SP (all closed by 1826) and, finally those in SC (closed by 1829; Table 1). The only exception was the armação of Cabo Frio, which opened in 1740 and closed in 1767/8 due to its relatively low productivity (Edmundson

& Hart 2014). Attempts to resume whaling activities in SC between 1855 and 1857 proved to be fruitless due to the scarcity of whales (Ellis 1969).

The decline in whaling activities at the armações in southern Brazil is consistent with the collapse of southern right whale populations worldwide. Reports from Yankee whaling ships crossing from the South Atlantic to the South Pacific indicate that sightings of southern right whales became rare during the beginning of the nineteenth century (Townsend 1935, Smith et al. 2012). A similar pattern has also been described for other southern right whale stocks throughout the nineteenth century. Roux et al. (2015) report that southern right whale catches off south-west Africa by pre-modern whalers fell from 40 animals per voyage in the early nineteenth century to 0-18 per voyage after 1830. In eastern Australia and New Zealand, catches of the species decreased from hundreds of whales per year between 1827 and 1847, to a few dozen or only one from 1848 (Carroll et al. 2014).

In contrast to what was observed in southern Brazil, most armações in BA remained operational after the 1830s, as whaling continued in the region of Caravelas and near Baía de Todos os Santos until the 1920s (Table 1; Tavares 1916, Ellis 1969, Castellucci Jr. 2009). Annual catches in this period ranged from 120 to 400 individuals (Furniss 1909, Ellis 1969), very different from whale catches in SC, SP and RJ. It is evident that the armações in BA survived because they relied on catching humpback whales almost exclusively after 1830. Photographic documentation and accurate description of morphological features (Furniss 1909, Tavares 1916) clearly show that this species was targeted by armações in north-eastern Brazil. In addition, historical records indicate that the species was regularly seen and occasionally captured by Yankee whalers in this region in the nineteenth century (Townsend 1935, Smith et al. 2012). This distribution pattern is consistent with present-day data. The main breeding ground for humpback whales in the western South Atlantic is off the coast of BA (Siciliano 1995, Martins et al. 2001) and the species is currently found near Caravelas and Baía de Todos os Santos in relatively large numbers (Andriolo et al. 2010b).

RECONSTRUCTING PRE-MODERN WHALING HUMPBACK WHALE CATCHES

Data on the production of whale oil has been used to infer the number of whales captured when the target species is known (Starbuck 1964, Mitchell & Reeves 1983, Best 1987). This approach is useful for estimating catches off Brazil as well because although catch numbers were not recorded, the quantity of oil produced in certain years was (Tavares 1916, Castellucci 2005).

Whale oil yield varies according to species, body size, nutritional condition, sex, reproductive stage, time of year, and carcass processing efficiency. Mitchell and Reeves (1983) suggest an average of 25 barrels for each humpback whale, based on the diaries of whalers who operated in the breeding grounds of the West Indies. This number is supported by the range of 25 to 30 barrels per animal reported for humpback whales captured off South Georgia (Risting 1928).

Oil production from whaling off BA was recorded in three different units: litres, kilograms and "canadas" (Tavares 1916, Castellucci 2005). One kilogram of whale oil corresponds to 0.931 l (Dieterichs 1916), and one "canada" corresponds to 2.662 l (Castellucci, 2005). Assuming the average oil yield of 25 or 30 barrels for each humpback whale (Risting 1928, Mitchell & Reeves 1983) and that each barrel corresponds to 132.49 l (Ellis 1991), we estimated humpback whale catches for armações in BA for 1856-1861, 1878-1881, 1901-1905 and 1908-1914 (Table 2).

Table 2. Numbers of humpback whales caught, estimated from the recorded production of oil, for various years and locations, and the sources of information. Estimates are based on a yield of 25 and 30 barrels of oil per whale.

Source	Year	Locality	Oil production (unit)	Catches (assuming 25 barrels/whale)	Catches (assuming 30 barrels/whale)
Castellucci (2005)	1856	Itaparica	1,250 (canadas)	0.142	0.118
Castellucci (2005)	1857	Itaparica	3,833.5 (canadas)	0.435	0.362
Castellucci (2005)	1858	Itaparica	2,762.5 (canadas)	0.313	0.261
Castellucci (2005)	1859	Itaparica	4,600 (canadas)	0.522	0.435
Castellucci (2005)	1860	Itaparica	8,000 (canadas)	0.907	0.756
Castellucci (2005)	1861	Itaparica	18,000 (canadas)	2.041	1.701
Castellucci (2005)	1878	Itaparica	50,000 (litres)	15.1	12.58

Castellucci (2005)	1879	Itaparica	50,000 (litres)	15.1	12.58
Castellucci (2005)	1880	Itaparica	50,000 (litres)	15.1	12.58
Castellucci (2005)	1881	Itaparica	20,000 (litres)	6.04	5.032
Tavares (1916)	1901-1905	Caravelas	4,919,539 (litres)	1,485.26	1,237.72
Tavares (1916)	1908	Bahia	1,253,976 (kg)	406.65	338.87
Tavares (1916)	1909	Bahia	703,170 (kg)	228.03	190.02
Tavares (1916)	1910	Bahia	760,511 (kg)	246.62	205.52
Tavares (1916)	1911	Bahia	1,021,993 (kg)	331.42	276.18
Tavares (1916)	1912	Bahia	1,510,794 (kg)	489.93	408.28
Tavares (1916)	1913	Bahia	921,780 (kg)	298.92	249.1
Tavares (1916)	1914	Bahia	996,309 (kg)	323.09	269.24

Catch estimates for the period 1856 to 1881 are low; in some cases, the unrealistic numbers less than one clearly do not represent the real catches of whales during that period. These low numbers occur because Castellucci (2005) only reported the production of oil destined for export. Ellis (1969) indicated that most of the oil produced by the armações in the mid to late 1800s was for domestic consumption, because the Brazilian product was considered of too low quality for the international market, and workers had limited knowledge of the techniques needed to preserve the oil before shipping it across the sea to Europe (Ellis 1969).

Starting in 1911, the estimated catches presented in Table 2 correspond to whales taken both by using pre-modern and modern whaling methods. This occurs because the oil production figures provided by Tavares (1916) combine oil obtained from catches made from armações in Caravelas with those in Itaparica, which, at the time, was already using modern techniques.

Based on the existing data on oil production and the historical catch records from the armações (Furniss 1909, Tavares 1916, Ellis 1969), we attempted to reconstruct minimum and maximum catch record series for humpback whales in north-eastern Brazil, adopting a rationale similar to that used by Mitchell and Reeves (1983) to describe the catch history of North Atlantic humpback whales in their Caribbean breeding grounds. For completeness, we

also included some information regarding catches made by Yankee whalers along the eastern coast of South America (Lodi 1992, Smith et al. 2006). We established 1830 as the starting year for captures because, at that time, southern right whale catches had already collapsed and there is evidence whalers in BA had directed their efforts to humpback whales.

In reconstructing the catch statistics, we must point out that there are some inconsistencies in the catch records for armações in north-eastern Brazil in the nineteenth century. Ellis (1969) indicated that nearly 120 to 200 animals were captured per year in BA after the closure of the armações in southern Brazil. These numbers are similar to those provided by Tavares (1916), who reported the capture of about 200 whales per year in BA. However, Furniss (1909) presented slightly higher annual catches: between 300 and 400 animals. Furniss (1909) and Ellis (1969) do not specify whether the numbers they provided correspond to the catches per armação or for all armações combined. However, Tavares (1916) indicated that the catches he reported were for the whole state of BA and therefore included all armações. Because information for years in which oil production data are available do not support annual captures of 120 to 400 whales per armação, we interpret the catches reported by Furniss (1909) and Ellis (1969) to refer to the overall annual catch in BA, which is consistent with the description of Tavares (1916).

Smith et al. (2006) report that 1174 humpback whales were killed by the Yankee whalers in the Southern Hemisphere, and that 1164 of them (99%) were captured between 1800 and 1900. They estimated that 209 of these whales were caught in the western South Atlantic: 28 in the 1840s and 181 in the 1860s. However, only approximately 10% of the logbooks from Yankee whaling voyages between 1780 and 1920 were examined, so these numbers are severe underestimations. In addition, Lodi (1992) mentions that Yankee whalers in one ship harpooned and processed at least 48 whales at the Abrolhos Bank in 1894.

Catches made by armações in Caravelas between 1911 and 1924 were estimated by using the minimum number of 30 whales (Tavares 1916) and a maximum of 50 (Lodi 1992). We consider 1924 to be the end of the pre-modern Brazilian whaling in this estimate, because Paiva (1965) indicates this as the precise year in which the last whale was captured in Caravelas. Minimum and maximum estimates of pre-modern humpback whale catches are presented in Table 3. Minimum estimates include the lowest catches provided by Furniss (1909), Tavares (1916), Ellis (1969) or, if available, the lowest catch estimated from oil production (Table 2, assuming an average of 30 barrels/whale), whichever is less. Maximum estimates include the largest estimate by Furniss (1909), Tavares (1916), Ellis (1969) or the highest estimate from oil production (Table 2, assuming an average of 25 barrels/whale),

whichever is greater. In either case, we add captures made from the Yankee ships along the Brazilian coast between 1840 and 1894 (Lodi 1992, Smith et al. 2006).

Table 3. Pre-modern period (1830 – 1910) capture data for humpback whales off the Brazilian coast, minimum and maximum numbers of animals captured, catches made by Yankee (North American) whalers, and estimates based on oil production (25 and 30 barrels/whale), for the years for which such information is available.

Year or Period	Minimum number/ Armações	Maximum number/ Armações	Yankee whaling ships	Minimum Oil Production (30 barrels/whale)	Maximum Oil Production (25 barrels/whale)	Minimum catch	Maximum catch
1830 – 1839	1,200[1]	4,000[2]	-	-	-	1,200	4,000
1840 – 1849	1,200[1]	4,000[2]	2.8	-	-	1,228	4,028
1850 – 1859	1,200[1]	4,000[2]	-	-	-	1,200	4,000
1860 – 1869	1,200[1]	4,000[2]	18.1	-	-	1,381	4,181
1870 – 1893	2,640[1]	8,800[2]	-	-	-	2,640	8,800
1894	120	400	48	-	-	168	448
1895 – 1900	720[1]	2,400	-	-	-	720	2,400
1901 – 1902	240[1]	800[2]	-	302.76[5]	363.31[5]	542.76	1,163.31
1903	120	400	-	-	-	120	400
1904 – 1905	240[1]	800[2]	-	302.76[5]	363.31[5]	542.76	1163.31
1906 – 1907	240[1]	800[2]	-	-	-	240	800
1908	120	400	-	338.87	406.65	338.87	406.65
1909	120	400	-	190.02	228.03	190.02	228.03
1910	120	400	-	205.52	246.62	205.52	246.62
1911 – 1924*	420[3]	700[4]	-	-	-	420	700
Total						**11,136.93**	**32,964.92**

[1] Assuming 120 individuals/year.

[2] Assuming 400 individuals/year.

[3] Assuming 30 individuals/year.

[4] Assuming 50 individuals/year.

[5] Oil production only in Caravelas.

* Only catches from armações in Caravelas.

CONCLUSIONS

Here we present a review of pre-modern whaling operations from armações along the coast of Brazil and updated catch records for humpback whales in the western South Atlantic

during the nineteenth and early twentieth century. We show that both southern right whales and humpback whales were captured between the early 1600s and the early 1900s, and that humpback whales were captured in much greater numbers than previously thought.

In southern Brazil (RJ, SP and SC), coastal whaling operations began in the 1620s and ended in the 1830s, with declines in catches and the subsequent collapse of the main target species: the southern right whale. There is evidence that humpback whales were captured in small numbers off southern Brazil, but it is difficult to describe these catches quantitatively with the available information. However, the closure of armações in RJ, SP and SC after the collapse of the southern right whale population suggests that humpback whale abundance in southern Brazil was not sufficient to maintain commercially viable whaling, and indicates that catches may have always been small.

In north-eastern Brazil (BA), catches with pre-modern whaling methods began in the early 1600s and only ended with the introduction of modern techniques in the early 1900s. Armações remained operational in BA after the 1830s, showing that they were not affected by the decline in the number of southern right whales observed further south. The persistence of armações in north-eastern Brazil was probably due to the high density of humpback whales in the region, which became the main target species in the nineteenth century.

We estimate that between 11000 and 32000 humpback whales were taken at the armações in north-eastern Brazil between 1830 and 1924, a number substantially greater than previously estimated. However, it is likely that pre-modern humpback whale catches off Brazil were greater. This species probably represented a significant fraction of the catches in the north-east prior to the collapse of southern right whale populations in the early 1800s. Existing records do not provide unequivocal evidence that southern right whales constituted the bulk of the catches in the north-east, and current and historical distribution patterns show that southern right whales may not have been abundant there. On the other hand, the north-eastern coast of Brazil is an important historical and current breeding habitat for humpback whales. It is therefore plausible that whalers may have relied on capturing this species if southern right whales were not as abundant as humpback whales, or if they were declining during the 1600s and 1700s.

The effects of pre-modern whaling on the western South Atlantic humpback whale population have never been measured, and the population status estimated by Zerbini et al. (2011) may be optimistic. Therefore, a new population assessment, which includes the pre-modern catches summarized here, is necessary, to evaluate the effect of this additional information on the current population status. Additionally, in order to improve estimates of pre-modern whale catches, we recommend checking older records of whaling activity in

colonial Brazil, if they are available. Such records could help to clarify whether southern right whales were really the target species for the armações in north-eastern Brazil before 1830, or whether they were killed only sporadically and humpbacks catches always predominated since exploitation started in 1602. Answering this question can lead us not only to a better understanding of the past, but also to more accurate knowledge about southern right whale and humpback whale recovery in the western South Atlantic.

ACKNOWLEDGEMENTS

The authors are grateful to the Cetacean Society International, the Society for Marine Mammalogy and the Brazilian Council for Scientific Research (CNPq) for grants to aid this study.

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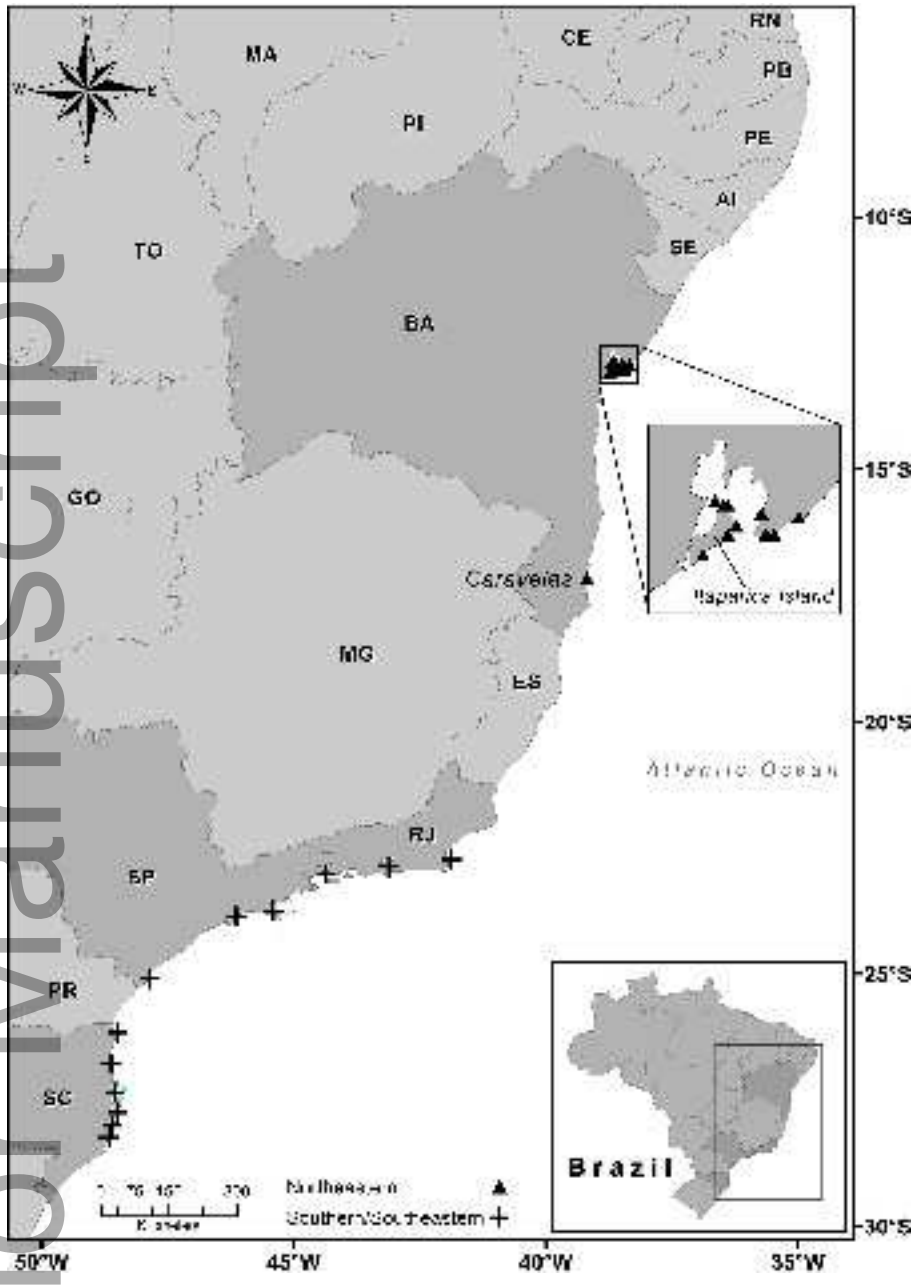

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